■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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Of Interest to Managers

Ted Sommer (DWR), tsommer@water.ca.gov

This issue's Quarterly Highlights begin with an update on the high-profile Collection, Handling, Transport, and Release (CHTR) program for the Delta fish salvage facilities. The program is designed to provide new information on how much potential there is for improving the survival of fish (including the federally listed delta smelt) during the CHTR process; these data will be used as the basis for decisions about future improvements to the fish facilities. Bob Fujimura and colleagues report that much of the 2004 work has been deferred to 2005 due to delays in the availability of equipment and facilities; however, the team has made progress on the development of techniques for fish holding and handling, physiological sampling methods, and predation assessment.

Kelly Souza's update on Spring Kodiak Trawling represents a good example of the progress that has been made in sampling for delta smelt. Based on initial studies during the late 1990s, Kodiak trawling was added to the IEP monitoring program in 2002 because it is a relatively efficient method to capture adult delta smelt. Souza's article reviews how the 2004 survey was used to identify the spawning distribution in the Delta. The survey provides valuable "early warning" information for water project operations about the expected distribution of young smelt during spring. One of the unexpected findings has been the presence of substantial numbers of spawners in the Sacramento Deep Water Ship Channel during each of the past two years.

This issue includes Katie Perry's article about Central Valley steelhead rainbow trout genetics. This much-anticipated study was initiated in 1999, following the federal listing of Central Valley steelhead in 1998. The goal was to provide information about the genetic structure of Central Valley steelhead to support management decisions about the species. The genetic analysis included anadromous and resident life history types[1], as well as fish produced in hatcheries. The sampling area covered a broad region, ranging from the northern Sacramento River (Clear Creek) to San Joaquin River tributaries in the south, and included sampling above and below dams on some rivers. Despite the substantial modifications to Central Valley stream habitats, the study revealed that there is still significant genetic diversity (population structure) of Central Valley steelhead rainbow trout. Overall, the genetic variation was relatively high within different valley tributaries. Surprisingly, there was little genetic difference between the Sacramento and San Joaquin drainages, suggesting that the populations originated from the same stock. Another major finding was that the hatchery populations were genetically similar to fish collected downstream of each hatchery. The genetic evidence supports the conclusion of NOAA Fisheries and the CA Department of Fish and Game that the species has undergone a recent reduction in population size.

River sediments represent key issues for flood management and water supply, because sediments affect reservoir capacity and river channel conveyance; navigation, because sediments can block channels; contaminant transport, because many contaminants are bound to sediments; and aquatic organisms because sediments are needed to maintain existing habitats and construct new ones. Andrey Shvidchenko, Robert MacArthur, and Brad Hall have analyzed historical sedimentation patterns in the Sacramento-San Joaquin Delta and compared them to recent trends. Like earlier studies, their review indicates that sedimentation was much higher during the early 20th century because of transport from hydraulic mining. Over last half century, there has been a steady decline in sediment inflow to the Delta. The authors estimate that most of the present sediment load comes from the Sacramento River (83%), which includes the Yolo Bypass. Their analyses suggest that 33% of the sediment input is transported by flow out of the Delta and 21% is diverted into the water export facilities; the remainder is deposited in Delta habitats. Of the amount deposited in the Delta, about half is removed by dredging.

Finally, this issue of the IEP Newsletter contains an impressive list of new scientific papers on different aspects of the San Francisco estuary. The list includes 20 articles published in the IEP-sponsored volume, "Early Life History of Fishes in the San Francisco Watershed".

1. Anadromous fish hatch in freshwater, then later migrate to the sea. Resident fish are those that remain in freshwater for their entire life cycles.

IEP QUARTERLY HIGHLIGHTS

April-June 2004

Collection, Handling, Transport, and Release Program for the Delta Fish Salvage Facilities

Bob Fujimura, Geir Aasen, Virginia Afentoulis, and Jerry Morinaka (DFG), bfujimura@delta.dfg.ca.gov

In winter 2004, we obtained formal approval of three study elements to assess the effects of the terminal phase of the fish salvage process at the State Water Project's John E. Skinner Delta Fish Protective Facility (Skinner Facility). The spring 2004 activities focused on the construction of testing facilities at the Skinner Facility, technical training, pilot testing, refinement of study protocols, and preparation of standard operating procedures. Formal tests planned for winter and spring 2004 have been deferred to 2005 due to delays in the completion of the test facility and the availability of essential equipment.

A 2,400 square-foot building and fish tanker release system were constructed near the fish salvage facilities and UC Davis' Delta Smelt Aquaculture Project facilities. A high-volume water system was installed to support holding tanks for fish in the test building and to fill a large pool used to recover fish released from the tanker trucks. Water filtration, ultraviolet (UV) sterilization, and refrigeration equipment was installed to support up to 28 circular fish tanks used to observe delta smelt after exposure to Collection, Handling, Transport, and Release (CHTR) experiments. DWR's Delta Field Division is modifying a fish tanker truck to provide support for these studies.

Jerry Morinaka and his staff are involved with the evaluation of acute mortality and injury of delta smelt associated with CHTR. They focused most of their time on the final installation of the fish holding tanks, fish recovery equipment, and water treatment equipment. Additional time was spent training staff to handle and transport fish more effectively, assess fish injuries, and operate equipment. They found several techniques that can be successfully used to handle delta smelt.

Virginia Afentoulis and her staff completed pilot tests for the Diagnostic Indicator Study that collected blood plasma from adult delta smelt that were exposed to various handling and holding conditions. Plasma samples were obtained from groups of cultured delta smelt at different intervals within a 48-hour post-exposure period. UC Davis' Clinical Endocrinology Laboratory will determine the cortisol concentration from the plasma samples using the enzyme-linked immunoassay method. Plasma cortisol is one of several methods examined to assess stress levels in delta smelt. Pilot tests showed that plasma collection from adult delta smelt can be successfully conducted at the fish facilities and that hematocrit readings were not a useful stress indicator. Afentoulis's studies were done in close collaboration with staff at USBR's Tracy Fish Collection Facility (Tracy Research staff) and were only possible this season by using their Tracy Aquaculture Facility. The Diagnostic Indicator Study will evaluate stress assessment methods, investigate stress effects on consecutively higher levels of biological organization, and determine the ecological significance of facility-induced stress on delta smelt.

During winter 2004, Geir Aasen and his staff continued pilot studies on the extent of fish predation within the CHTR phase. With the support of USBR's Tracy Research staff, a second series of pilot tests was used to determine the rate of digestion of consumed prey fish in controlled feeding trials at USBR's Tracy Aquaculture Facility. By examining the degree of digestion of artificially raised fish fed to striped bass (*Morone saxatilis*) after timed intervals, we can better determine whether fish found in stomach samples were likely consumed during the CHTR phase. Preliminary observations suggest that prey items can undergo varying degrees of digestion when several fish are found in the stomach. Lab work was completed for stomach samples collected in an earlier series of pilot tests conducted in fall 2003. This initial pilot study examined wild predatory fish taken from two points within the CHTR process. Databases have been created and data entry has been completed for both studies.

Spring Kodiak Trawl Results from the San Francisco Estuary, 2004

Kelly Souza (DFG), ksouza@delta.dfg.ca.gov

The 2004 Spring Kodiak Trawl (SKT) survey, conducted by the California Department of Fish and Game (DFG), ran from 12 January 2004 to 20 May 2004. The objective of the SKT is to identify delta smelt (*Hypomesus transpacificus*) distribution and provide water managers and fisheries regulators with information on areas of potential spawning. This information is of particular interest when the distribution of delta smelt favors the eastern or southern Delta, which can lead to increased salvage of adults and subsequent juvenile populations. In addition to detecting distribution of adult delta smelt, the SKT survey also monitors the gonadal maturation of male and female delta smelt to determine the proportion of catch that is unripe, ripe, and spent for each sampling survey.

The SKT employs two alternating sampling regimes. The Delta-wide surveys (numbered 1-5), designed to monitor the distribution of delta smelt, took up to 5 days to complete and sampled 39 stations from the Napa River to Ryde on the Sacramento River and to the city of Stockton on the San Joaquin River (Figure 1). Supplemental surveys (numbered 11-15), designed to monitor the reproductive maturity of delta smelt, took up to 2 days to complete and were conducted in areas of greatest delta smelt density. Density was indicated by the catch data of the previous Delta-wide portion of the SKT survey. During 2004, 5 Delta-wide and 5 supplemental surveys were completed.

Gear and gear deployment methods were previously described in Souza (2002). All fish caught were speciated, enumerated, and measured to the nearest millimeter for fork length (FL) or total length (TL). Sex and reproductive stage (adapted from R. Mager, personal communication) was recorded for all adult delta smelt. Additionally, subsamples of stage 4 (ripe) females were preserved in ethanol (heads) and 10% buffered formalin (bodies) to be used later for age and fecundity evaluations being conducted by other researchers.

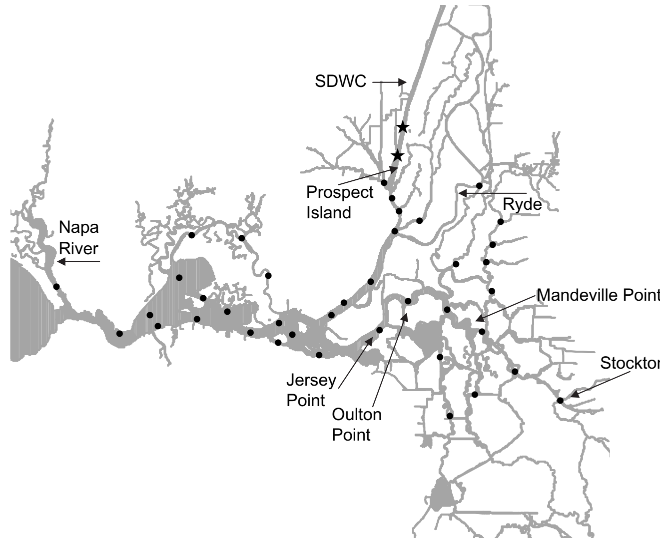

Figure 1 Existing locations of sampling stations (•) and proposed stations (★) in the Sacramento Deep Water Channel (SDWC) for the CA Department of Fish and Game's Delta-wide Spring Kodiak Trawl Survey in the San Francisco Estuary, California.

Catch data from both the Delta-wide and supplemental surveys were combined and then adjusted to account for the frequency of temperature and specific conductance readings so that more frequent readings were not overrepresented. Water temperature was grouped into 2 °C increments and specific conductivity was grouped by 1,000 μS increments. Total catch of delta smelt in each group (separated by sex and maturity stage) was divided by the number of times the respective group was represented (frequency of reading).

Ninety-nine percent of spawning fish (stage 4 females and stage 5 males) were collected at temperatures 10 °C or above, and 100% of spent fish (stage 6 females and males) were collected at temperatures 12 °C or above (Figure 2A and 2B). Smelt in maturity stages prior to spawning (stage 2, 3, and 4 males; stage 2 and 3 females) were collected across all specific conductivity groups (Figures 2C and 2D). Spawning and spent delta smelt were more limited in their distribution and were mainly found at specific conductivities less than 4,000 μS/cm (spawning fish) and less than 3,000 μS/cm (spent fish) (Figures 2C and 2D).

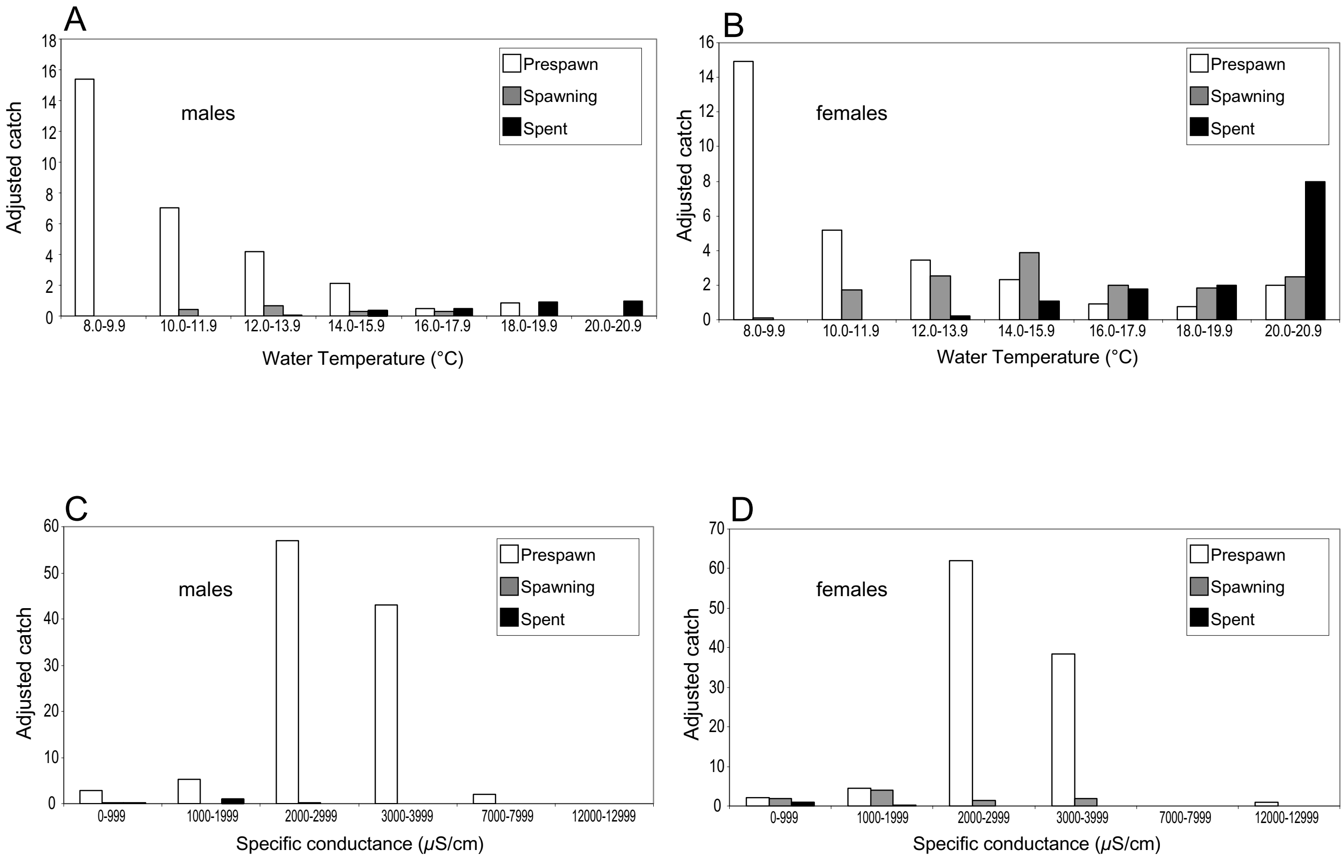

Figure 2 Male and female delta smelt catch (by maturity status) adjusted for frequency of water temperature readings (°C) (A and B) and frequency of specific conductivity readings (μS/cm) (C and D), 2004 Spring Kodiak Trawl, Delta-wide and supplemental surveys combined.

Delta-wide Surveys

The Delta-wide portion of the 2004 SKT survey collected a total of 4,592 fishes representing 27 species from 10 families. Three families comprised 925% of the catch: Clupeidae (43%), Salmonidae (26%), and Osmeridae (23%). The most common fishes encountered were threadfin shad (*Dorosoma petenense*), followed by Chinook salmon (*Oncorhynchus tshawytscha*) and delta smelt. Based on release confirmation notices from the US Fish and Wildlife Service (USFWS), it is likely that the large juvenile Chinook salmon catches were due to hatchery releases that coincided with our sampling efforts.

Delta smelt were most numerous and most widely distributed during survey 1, when they were collected from Napa River to Cache Slough and in the eastern Delta. Survey 1 also accounted for the largest numbers of delta smelt caught; catch decreased with each subsequent Delta-wide survey (Table 1). The majority of delta smelt caught during surveys 1-3 came from Montezuma Slough; the catch had shifted east towards the confluence of the Sacramento and San Joaquin rivers by survey 5. Distribution from the 2004 SKT was similar to that found during 2002 when Montezuma Slough accounted for the largest concentration of delta smelt in all surveys (Souza 2002).

Both 2002 and 2004 differed from the 2003 SKT when the largest concentration of delta smelt occurred in Cache Slough for 3 of the 4 surveys (Souza 2003). Catch in Cache Slough for all 2004 surveys combined accounted for only 1.3% of the entire delta smelt catch; this was similar to 2002 when catch in Cache Slough accounted for 4.1% of the entire delta smelt catch. If this difference was due to survey timing, which was deliberately delayed during 2003, larger numbers of delta smelt catch in Cache Slough would have been expected later in the season; this shift never occurred. Instead, most of the ripe individuals (Figure 3) and spent fish (Figure 4) were found in the lower San Joaquin River and lower Sacramento River areas.

Table 1 Catch and sex ratios of adult delta smelt caught during Delta-wide and supplemental surveys of the Spring Kodiak Trawl, 2004.

Date	Survey	Males	Females	Total	M:F Sex ratio
Delta-wide surveys					
1/12 - 1/15	1	189	182	380	1:1
2/09 - 2/17	2	134	165	300	1:1
3/08 - 3/12	3	110	85	196	1:1
4/05 - 4/08	4	7	55	62	1:8
5/03 - 5/07	5	3	9	13	1:3
Supplemental surveys					
1/26 - 1/27	11	301	322	630	1:1
2/23 - 2/24	12	116	102	220	1:1
3/22 - 3/23	13	27	27	54	1:1
4/19 - 4/20	14	24	100	125	1:4
5/20	15	3	66	71	1:22
Total		914	1,113	2,051	

Supplemental Surveys

Distribution during the Delta-wide surveys in 2004 favored the San Joaquin River system, especially during the earlier surveys. Therefore, most of the supplemental surveys were conducted in parts of the lower San Joaquin River between Jersey Point and Mandeville Point (Figure 1). Delta smelt were detected in these locations until late March (surveys 11-13) after which time no delta smelt were collected upstream of Oulton Point on the San Joaquin River.

Other areas where supplemental surveys were conducted included Montezuma Slough (surveys 11-13), the lower Sacramento River (survey 14), and the Sacramento Deep Water Channel (SDWC) (survey 15). In 2003 the SDWC was sampled frequently because catch in Cache Slough during the Delta-wide surveys consistently indicated the presence of numerous delta smelt (Souza 2003). That was not the case in 2004; insufficient numbers of delta smelt were collected in Cache Slough during any survey to warrant additional sampling in Cache Slough or the SDWC. However, few fish were caught during Delta-wide survey 5 (n = 13), providing no obvious sampling location for the supplemental survey; based on experience, sampling was directed to the SDWC during survey 15. Both adult (n = 71) and current year-class (n = 165) delta smelt were collected, as well as 2 juvenile wakasagi (*Hypomesus nipponensis*). Only 3 spent males were collected. Over half of the remaining 66 females were spent (58%), but 12% were in stage 3 (prespawn) and 30% were in stage 4 (spawning) (Figures 5-7). The male to female sex ratio was 1:22, which is consistent with past years in that the number of females collected in proportion to males increases as the season progresses. However, survey 15 had the most unbalanced male to female sex ratio (1:22) to date. This skewed sex ratio could be an artifact of sampling. If ripe males remained closer to spawning substrates awaiting females, they would be unavailable to the surface-towed Kodiak trawl.

The SKT was successful at describing the distribution of adult delta smelt. More than 2,000 adult delta smelt were collected this year, and for the first time we detected the current year-class of delta smelt as well. Sampling will continue next year, with a few modifications. Due to the large numbers of delta smelt collected in the SDWC, we will improve our spatial coverage by adding 2 stations within the SDWC (Figure 1). They will be located approximately 6 and 12 nautical miles above the southern end of Prospect Island. Additionally we will start the first survey during the latter half of January, and complete at least 4 (or 5 in cooler water years) Delta-wide surveys. A consistent number of surveys conducted at approximately the same time every year will enable us to create an index, adding value to project data over time. Future SKT surveys will not only provide information about the distribution of adult delta smelt, but also an index of relative abundance.

References

Souza K. 2002. Revision of California Department of Fish and Game's Spring Midwater Trawl and Results of the 2002 Spring Kodiak Trawl. IEP Newsletter 15(3):44-7.

Souza K. 2003. 2003 Spring Kodiak Trawl. IEP Newsletter 16(4):34-9.

Notes

Mager RC. (Department of Water Resources). 14 June 2002. E-mail communication.

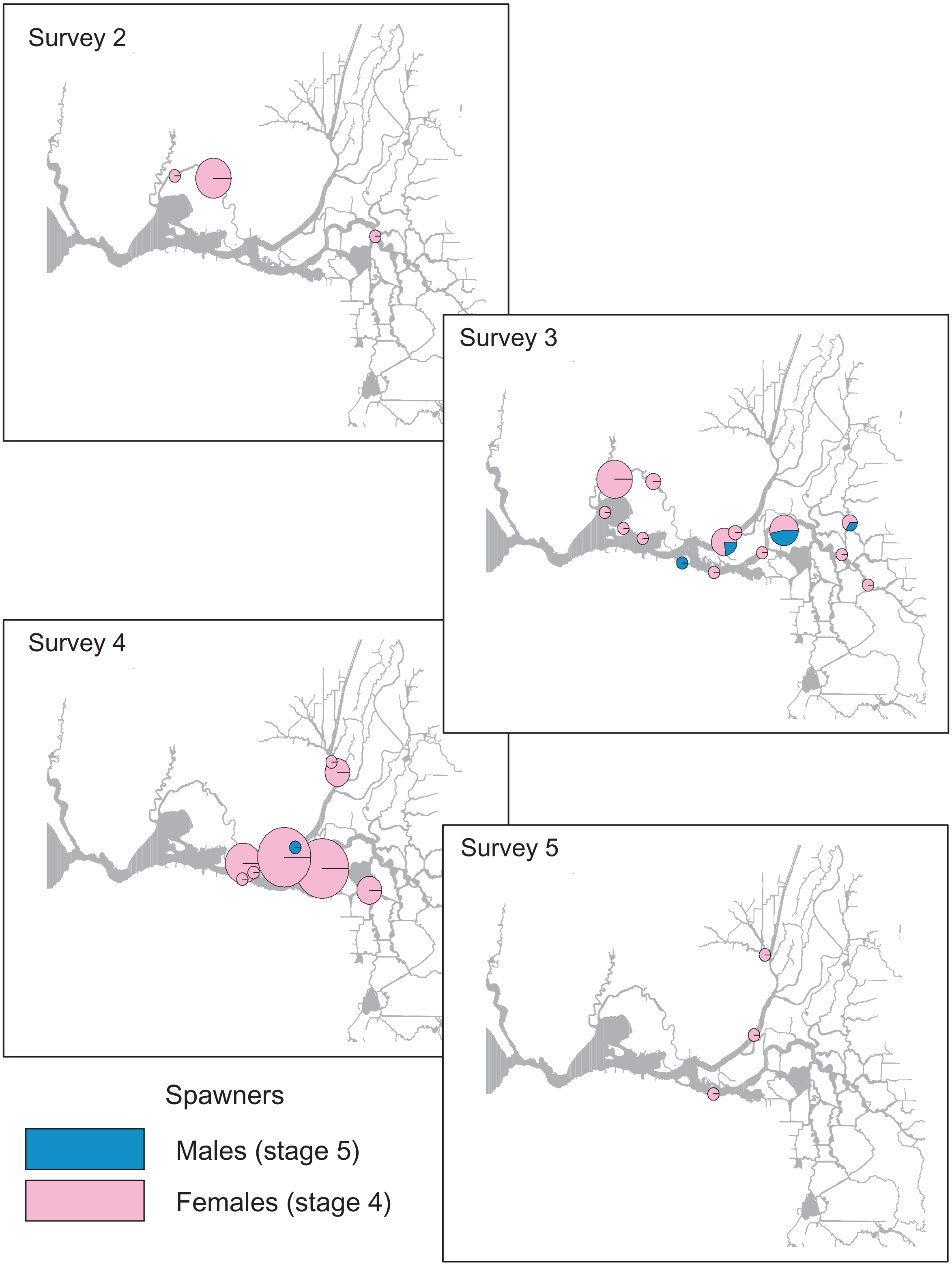

Figure 3 Distribution of spawning delta smelt collected during the 2004 Spring Kodiak Trawl's Delta-wide surveys. No spawning individuals were collected during survey 1.

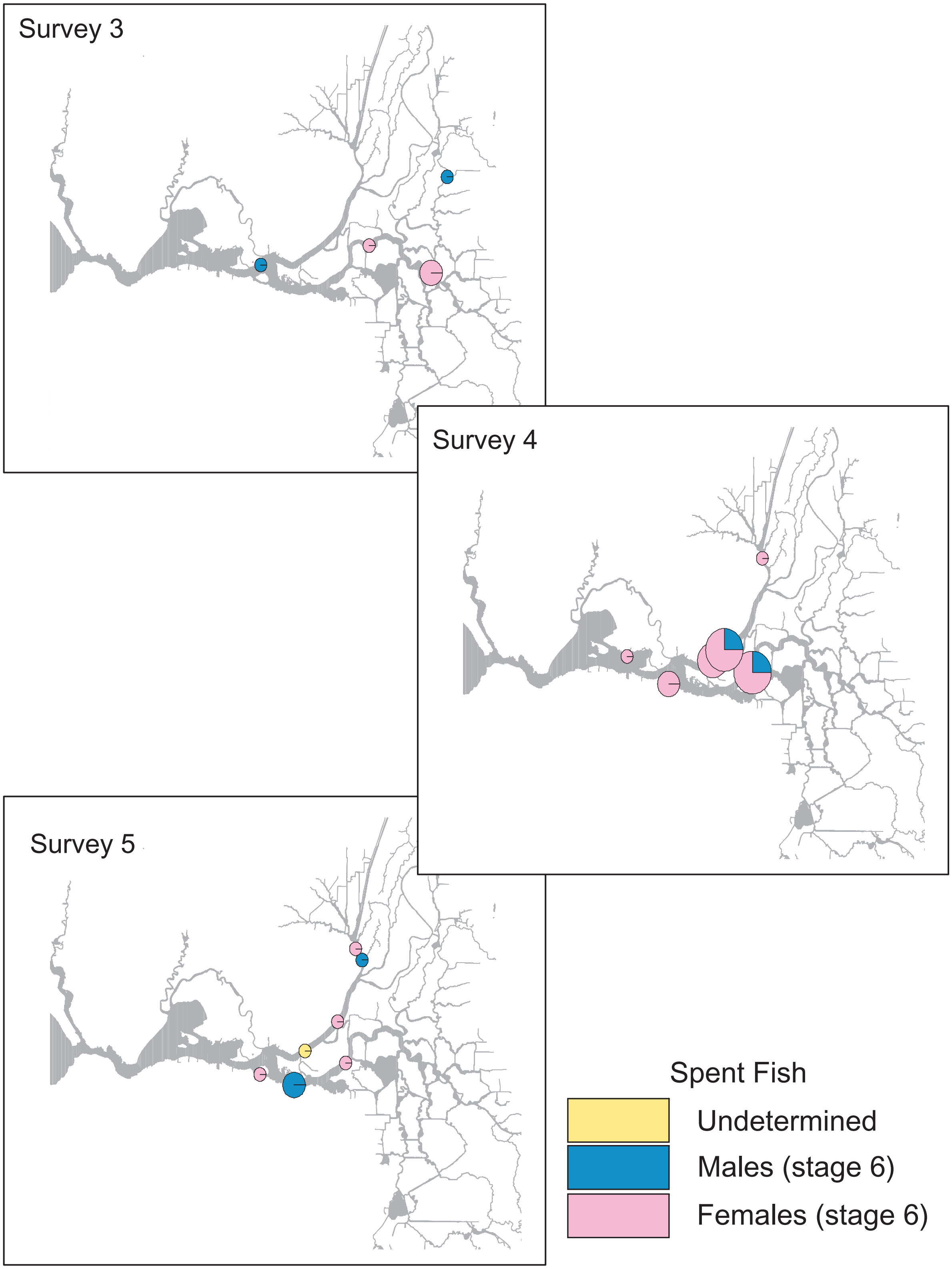

Figure 4 Distribution of spent delta smelt collected during the 2004 Spring Kodiak Trawl's Delta-wide surveys. No spent individuals were collected during surveys 1 and 2.

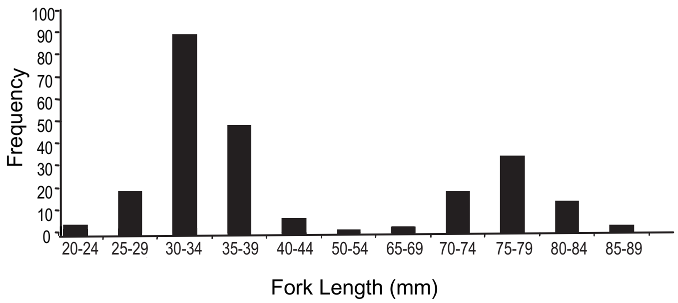

Figure 5 Length frequency of delta smelt collected during supplemental survey 15 of the 2004 Spring Kodiak Trawl.

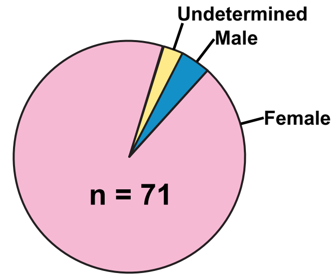

Figure 6 Adult sex ratio of delta smelt collected during supplemental survey 15 of the 2004 Spring Kodiak Trawl.

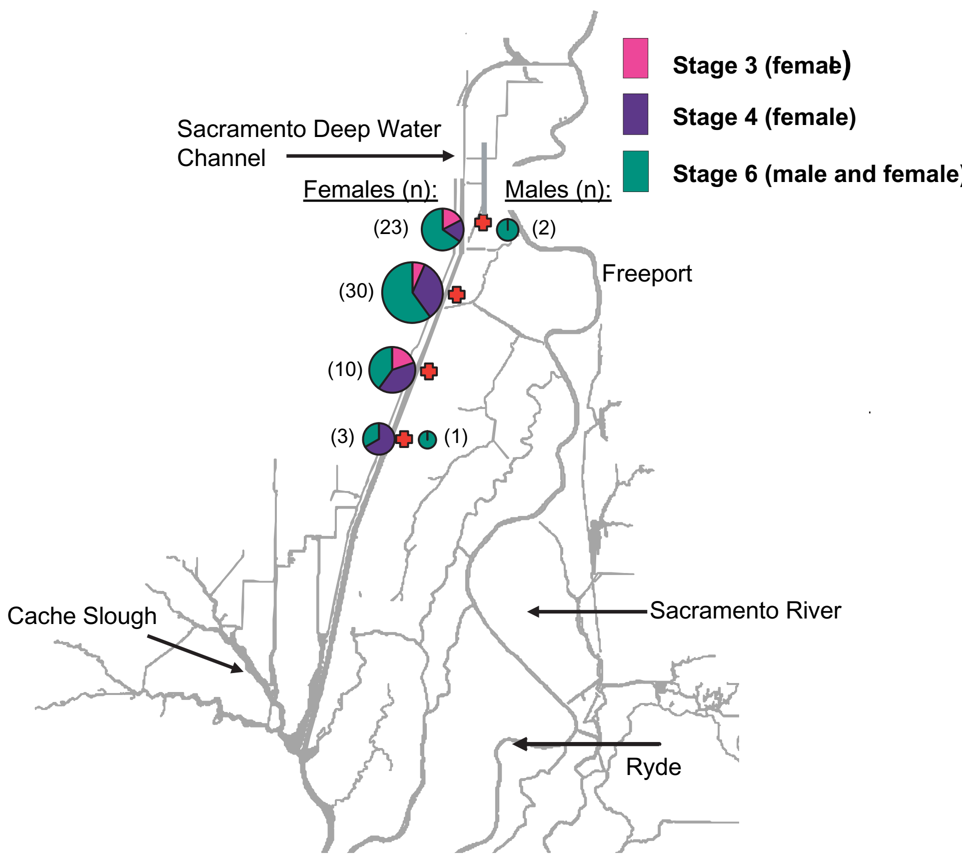

Figure 7 Maturity status of delta smelt collected during supplemental survey 15 of the 2004 Spring Kodiak Trawl.

Length-weight Relationships and Conversions for Fresh and Ethanol-preserved Age-0 Splittail

Fred Feyrer (DWR), ffeyrer@water.ca.gov

I conducted a modest study to evaluate the effects of ethanol preservation on the length and weight of age-0 splittail so that fresh measurements could be estimated from preserved specimens for ongoing age and growth studies. In this highlight I provide a brief synopsis of the results of this study, equations for length and weight relationships, and conversions for both fresh and ethanol-preserved fish.

I collected 71 age-0 splittail from the Sacramento River during 2003 for this study (standard length range = 19 to 46 mm; mean = 28 mm; standard deviation = 5 mm). Shortly after collection, each individual fish was measured to the nearest millimeter for standard length, fork length, and total length, and weighed to the nearest hundredth of a gram while either alive or freshly dead. The fish were then preserved in 95% ethanol in individual vials and measured at increasing time intervals after preservation: one day, seven days, and one year.

Effects were apparent within the first day of preservation. On average, individual fish lost about one millimeter in each length measurement due to preservation, with no relation to initial length. The simple effect of human error associated with measuring small fish to the nearest millimeter produced enough variation around the mean that preserved lengths were not statistically different overall from initial lengths (one-way ANOVAs for each length measurement, $P > 0.05$). In contrast, individual fish lost up to 47% of total body weight after preservation due to dehydration, and weight loss was negatively correlated with initial standard length ($r = 0.89$, $P < 0.001$) and total body weight ($r = 0.91$, $P < 0.001$). Although the variable effect of preservation on length versus weight is not surprising, it is important to document for future studies. Table 1 provides length-weight relationships for fresh and preserved fish, length conversions for fresh and preserved fish, and equations to convert preserved length and weight measurements to fresh measurements.

Table 1 Length-weight relationships and various conversions for age-0 splittail. All relationships are statistically significant at P < 0.05 and residual plots were examined to ensure the appropriateness of each model.

Data	*Equation*	r^2
Fresh length-weight relationships		
	$WT = 0.000028SL^{2.85}$	0.97
	$WT = 0.000012FL^{2.97}$	0.98
	$WT = 0.000011TL^{2.88}$	0.98
Fresh length conversions		
	$SL = -1.120 + 0.891(FL)$	0.98
	$SL = -0.275 + 0.762(TL)$	0.99
Preserved length-weight relationships		
	$WT = 0.000017SL^{2.88}$	0.98
	$WT = 0.000004FL^{3.16}$	
	$WT = 0.000004TL^{3.06}$	
Preserved length conversions		
	$SL = -2.81 + 0.950(FL)$	0.99
	$SL = -1.64 + 0.799(TL)$	0.99
Preserved-to-fresh length conversions		
	$SL_f = 1.99 + 0.963(SL_p)$	0.99
	$FL_f = 0.44 + 1.03(FL_p)$	0.99
	$TL_f = 0.79 + 1.01(TL_p)$	0.99
	$SL_f = -0.724 + 0.914(FL_p)$	0.97
	$SL_f = 0.359 + 0.770(TL_p)$	0.97
Preserved-to-fresh weight conversion		
	$WT_f = 0.048 + 1.448(WT_p)$	0.99

SL = standard length, FL = fork length, TL = total length, WT = total body weight, $_f$ = fresh, $_p$ = preserved.

Specific-Conductance and Water-Temperature Data for San Francisco Bay, California, for Water Year 2003

Paul A. Buchanan (USGS), buchanan@usgs.gov

Introduction

This article presents time-series graphs of specific-conductance and water-temperature data collected in San Francisco Bay during water year 2003 (October 1, 2002, through September 30, 2003). Specific-conductance and water-temperature data were recorded at 15-minute intervals at the following US Geological Survey (USGS) locations (Figure 1):

- Suisun Bay at Benicia Bridge, near Benicia, CA. (BEN) (site # 11455780)
- Carquinez Strait at Carquinez Bridge, near Crockett, CA. (CARQ) (site # 11455820)
- Napa River at Mare Island Causeway, near Vallejo, CA. (NAP) (site # 11458370)
- San Pablo Strait at Point San Pablo, CA. (PSP) (site # 11181360)
- San Pablo Bay at Petaluma River Channel Marker 9, CA. (SPB) (site # 380519122262901)
- San Francisco Bay at Presidio Military Reservation, CA. (PRES) (site # 11162690)
- San Francisco Bay at San Mateo Bridge, near Foster City, CA. (SMB) (site # 11162765)

Suspended-sediment-concentration data also were collected at most of these sites during water year 2003.

Specific-conductance and water-temperature data from PSP, PRES, and SMB were recorded by the CA Department of Water Resources (DWR) before 1988, by the USGS National Research Program from 1988 to 1989, and by the USGS-DWR cooperative program since 1990. BEN, CARQ, NAP, and SPB were established in 1998 by USGS. The monitoring station at PRES was discontinued on November 12, 2002, due to shoaling at the site.

Data Collection

Specific-conductance and water-temperature data were collected at near-surface and near-bottom depths in the water column to help define the vertical stratification. However, at the shallow SPB and PRES sites, data were collected only at near-bottom depth because the mean lower-low water depth[1] at these sites was about 6 feet.

Several types of instrumentation were used to measure specific-conductance and water-temperature data in San Francisco Bay. Instrument selection was site specific and was based on the availability of alternating-current power at the site. Specific conductance [reported in microsiemens per centimeter at 25 °Celsius (C)] was measured using either a Foxboro[2] electrochemical analyzer (calibrated accuracy ± 5%), a Hydrolab Datasonde 4[2] multiprobe (conductivity cell calibrated accuracy ± 3%) or a YSI 6920-M[2] multiparameter water quality logger (conductivity cell calibrated accuracy ± 3%). Water temperature (reported in degrees Celsius) was measured using a Campbell Scientific[2] thermister (accuracy ± 0.2 °C), a Hydrolab Datasonde 4[2] multiprobe (temperature probe accuracy ± 0.2 °C), or a YSI 6920-M[2] multi-parameter water quality logger (temperature probe accuracy ± 0.2 °C).

Monitoring-instrument calibrations were checked every 2-3 weeks. Calibration of the Foxboro[2] specific-conductance instrument was checked using an Orion model 140[2] conductivity meter (calibrated accuracy ± 2%), which was calibrated to a known specific-conductance standard (direct checks against a known standard are not possible with the Foxboro[2] large-bore probe because of the large volume of standard needed). Calibration of the Hydrolab[2] and YSI[2] specific-conductance instruments were checked using a range of known specific-conductance standards. Calibration of the water-temperature instruments were checked using a

1. The mean lower-low water depth is the average of the lower-low water height above bottom of each tidal day observed during the National Tidal Datum Epoch (NTDE). The NTDE is the specific 19-year period (1960-1978 for values given in this report) adopted by the National Ocean Service as the official time segment during which tidal observations are made and reduced to obtain mean values (Hicks, 1983).

2. The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by USGS or DWR.

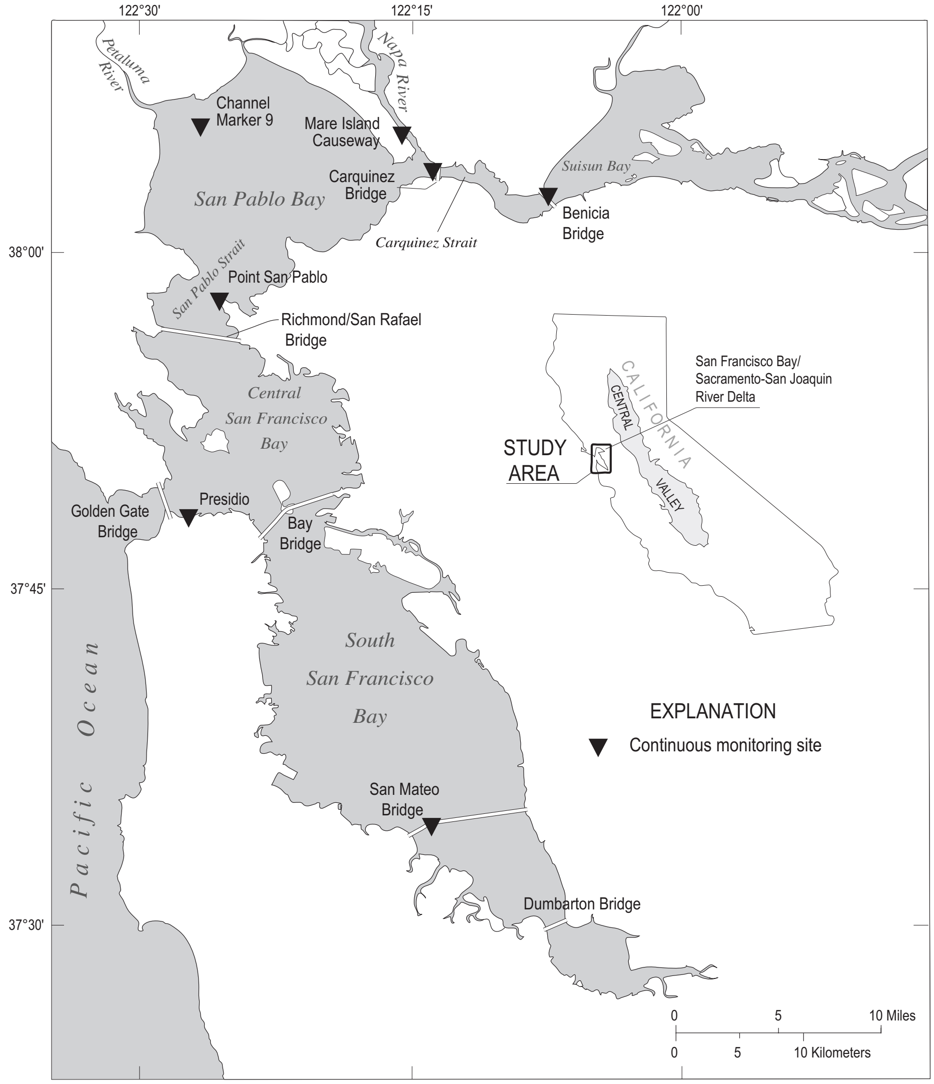

Figure 1 Specific-conductance and water-temperature data monitoring sites in San Francisco Bay, California.

Cole Parmer[2] thermister (accuracy ± 0.2 °C). Data corrections (necessary because of biological fouling or instrument electronic drift)—based on differences between the monitoring instrument readings and the field-calibrated instrument readings taken before and after cleaning—were applied to the record by following the guidelines described by Wagner and others (2000).

Data Presentation

Figures 2 through 7 show time-series graphs of the specific-conductance and water-temperature data measured at the seven sites in San Francisco Bay. Gaps in the data are caused primarily by equipment malfunctions and fouling. Tidal variability (ebb and flood) affects specific conductance and water temperature (Cloern and others, 1989; Ruhl and Schoellhamer, 2001). Tidal variability was greater in San Pablo Bay than in south San Francisco Bay (Schoellhamer, 1997). To illustrate tidal variability, Figure 8 shows the near-surface and near-bottom specific conductance and water-level data at Point San Pablo for the 24 hours of March 20, 2003.

Daily maximum and minimum values of specific-conductance and water-temperature data for the seven sites are published annually in Volume 2 of the USGS California water-data report series, which is available on the USGS website (USGS, accessed June 1, 2004). The complete data sets also are available (USGS, accessed June 16, 2004).

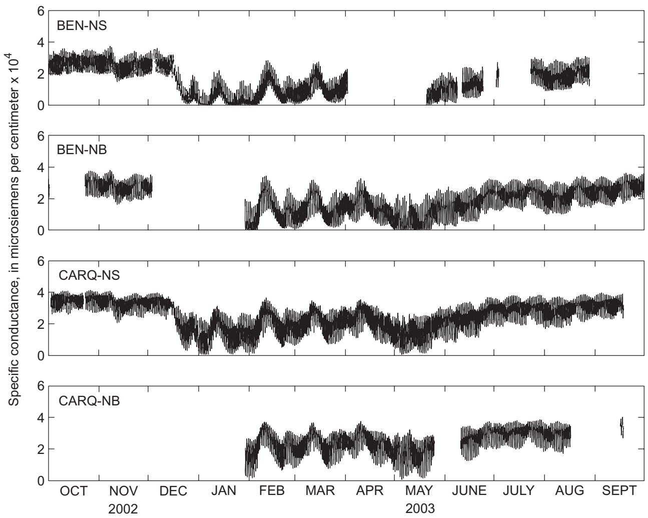

Figure 2 Near-surface (NS) and near-bottom (NB) measurements of specific conductance at Benicia Bridge (BEN) and Carquinez Bridge (CARQ), San Francisco Bay, water year 2003. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4).

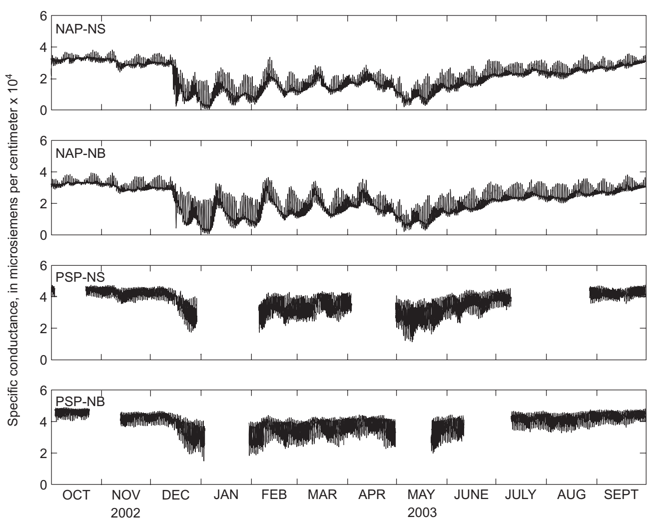

Figure 3 Near-surface (NS) and near-bottom (NB) measurements of specific conductance at Napa River (NAP) and Point San Pablo (PSP), San Francisco Bay, water year 2003. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4).

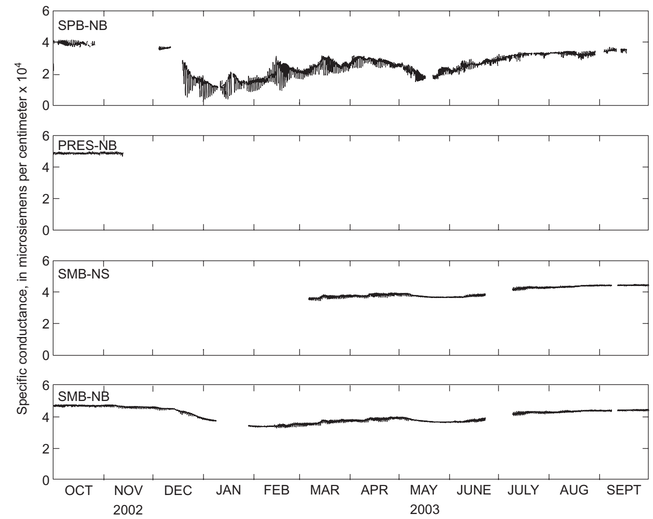

Figure 4 Near-bottom (NB) measurements of specific conductance at San Pablo Bay (SPB), Presidio (PRES), and near-surface (NS) and near-bottom (NB) measurements of specific conductance at San Mateo Bridge (SMB), San Francisco Bay, water year 2003. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4).

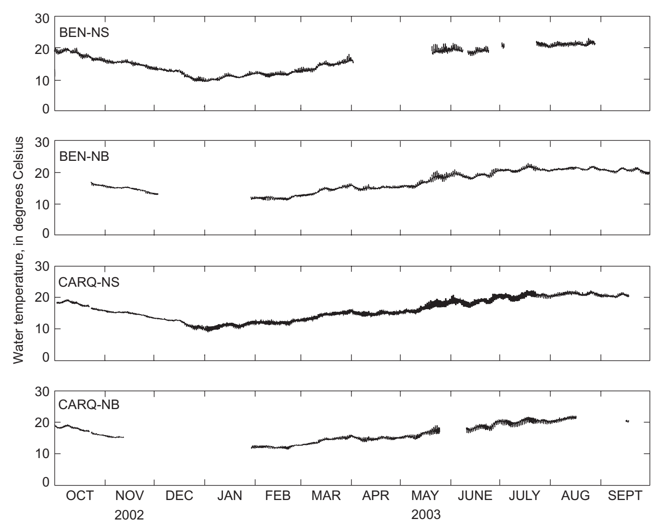

Figure 5 Near-surface (NS) and near-bottom (NB) measurements of water temperature at Benicia Bridge (BEN) and Carquinez Bridge (CARQ), San Francisco Bay, water year 2003.

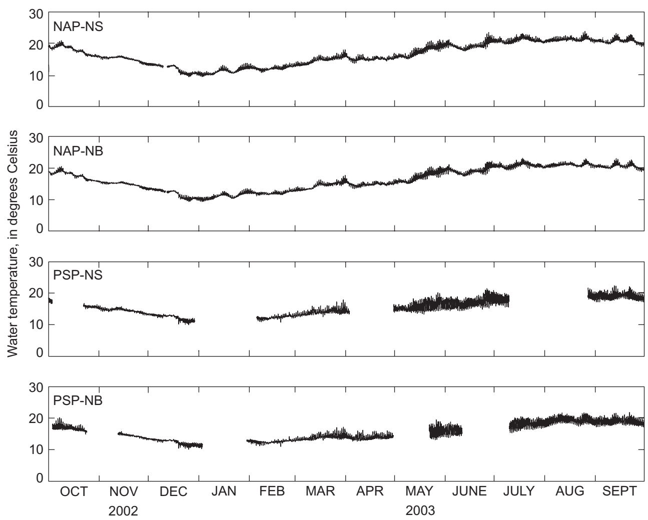

Figure 6 Near-surface (NS) and near-bottom (NB) measurements of water temperature at Napa River (NAP) and Point San Pablo (PSP), San Francisco Bay, water year 2003.

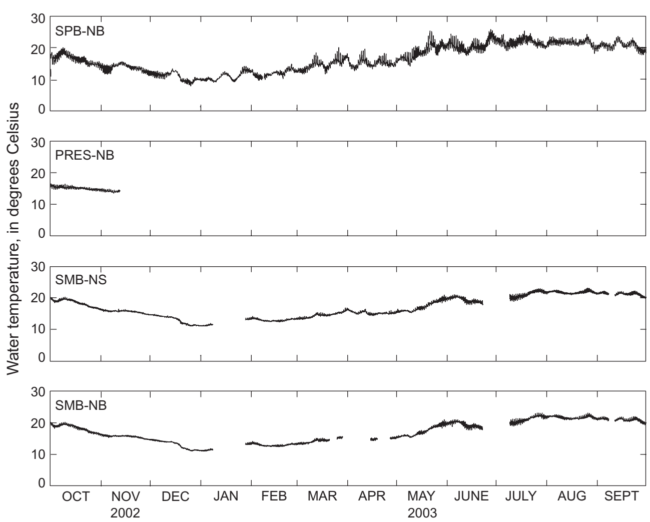

Figure 7 Near-bottom (NB) measurements of water temperature at San Pablo Bay (SPB) and Presidio (PRES), and near-surface (NS) and near-bottom (NB) measurements of water temperature at San Mateo Bridge (SMB), San Francisco Bay, water year 2003.

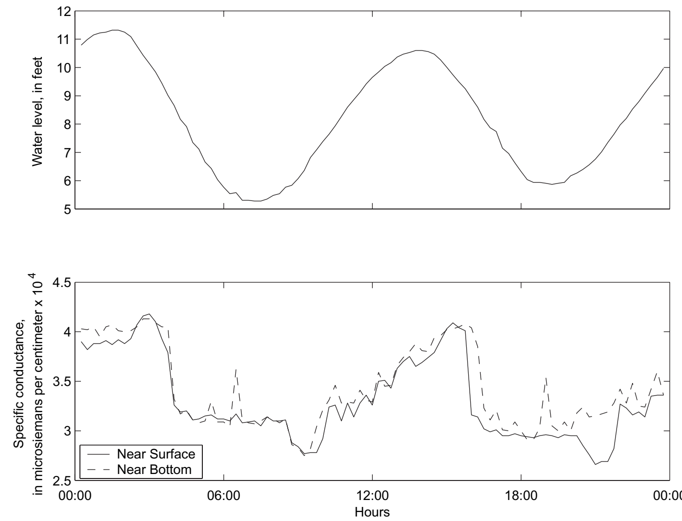

Figure 8 Near-surface and near-bottom measurements of specific conductance and water levels at Point San Pablo, San Francisco Bay, March 20, 2003. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4).

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The Population Genetic Structure of Central Valley Steelhead Rainbow Trout

Katie Perry (DFG), kperry@dfg.ca.gov

Introduction

In 1999 the Department of Fish and Game (DFG) obtained funding from the CALFED Bay-Delta Program, the Ecosystem Restoration Program, and the US Fish and Wildlife Service's (USFWS) Anadromous Fish Restoration Program (AFRP) to conduct a comprehensive baseline genetic analysis of coastal rainbow trout (*Oncorhynchus mykiss irideus*) in the Central Valley. This species exhibits great variation in life history, with anadromous (steelhead) and resident forms being the extremes of a continuum of life-history types. Central Valley steelhead have experienced declining abundance and their range has been greatly reduced due to the loss of historical habitat above dams. The federal Biological Review Team that conducted the status review for west coast steelhead concluded that resident rainbow trout should be included in the steelhead distinct population segments or Evolutionarily Significant Units (ESU) where they have the opportunity to interbreed (Busby and others 1996). However, National Oceanic and Atmospheric Administration (NOAA) Fisheries listed only the anadromous life-history form under the Endangered Species Act (ESA)[1]. In 1998, the Central Valley California Steelhead ESU was listed as threatened. Unfortunately, the genetic profiles and relationships of the different populations and life-history types occurring the Central Valley were not investigated and described prior to major impacts to the species, such as extensive habitat modification, habitat loss through construction of dams, and the introduction of non-native coastal rainbow trout (both anadromous and resi-

1. NOAA Fisheries published a new proposed rule on June 14, 2004, that includes resident rainbow trout where the two forms co-occur.

dent). NOAA Fisheries reviewed existing genetic analyses and conducted some additional analyses to delineate ESUs for purposes of the ESA (Busby and others 1996). However, their analyses did not provide sufficient detail necessary to distinguish populations within ESUs (McEwan 2001). DFG initiated this study to elucidate the genetic profiles of native Central Valley steelhead rainbow trout[1] and to describe population genetic structure in relation to anadromous and resident life-history types and anadromous hatchery populations.

The information from the Central Valley steelhead rainbow trout study will enable development of management actions that will accelerate the species' recovery. Analysis of the remaining amount and pattern of genetic variation within and among Central Valley steelhead populations will be used to estimate population structure and genetic diversity. Knowing the amount and pattern of genetic diversity will allow us to prioritize research and management to retain remaining genetic and biological diversity; to avoid mixing different groups of fish, which would lead to reduced genetic diversity; identify populations with relatively low diversity; identify populations of interbreeding individuals; and identify metapopulation structure. This study will help us identify the most appropriate steelhead stock to use as donors to reintroduce steelhead to stream systems where they have been extirpated. If native non-anadromous rainbow trout—which have been recently isolated from the ocean due to construction of impassable dams—prove to be genetically similar to anadromous forms in the same stream, these non-anadromous populations may have the potential to provide brood stock for reintroduction projects. Identification of these isolated populations, if they exist, could greatly enhance our ability to reintroduce native steelhead to Central Valley streams where they have become extirpated without risking reductions in genetic diversity. Another benefit will be the clarification of the genetic relationship of natural stocks with hatchery stocks. This will allow managers to (1) assess whether hatchery practices are having unintended genetic effects on the natural populations, such as introgression and loss of genetic variation, and (2) assess whether hatchery populations are significantly different from the natural populations from which they were founded.

1. The term "steelhead rainbow trout" is used to refer collectively to all life-history types.

Objectives

- Describe and compare genetic profiles and relationships between steelhead rainbow trout populations inhabiting specific stream systems within the Central Valley.
- Describe genetic profiles of Central Valley hatchery steelhead populations and compare to naturally-spawning, presumed native populations of steelhead and isolated resident rainbow trout.
- Analyze genotypes of self-sustaining, presumed native Central Valley rainbow trout populations that are now isolated above artificial barriers to determine their phylogenetic relationship to anadromous and non-anadromous rainbow trout populations and strains.
- Evaluate the genetic structure of naturally spawning Central Valley steelhead populations.

Methods

Sampling locations for tissue collections are shown in Figure 1 and described in Table 1. DFG collected, or coordinated the collection of, tissue samples from steelhead rainbow trout at 21 locations throughout the Central Valley. Several other agencies and consultants assisted with collections at various locations. USFWS made collections from upper and lower Clear Creek and Coleman National Fish Hatchery (CNFH) for a related study. Data from these locations are included in the analyses and results for a total of 24 sampling locations. Tissue samples were collected from rainbow trout captured in anadromous reaches and above artificial barriers, and taken from anadromous fish hatcheries from 1999 to 2003. Collections made above artificial barriers were below historical natural barriers and within the historical range of steelhead, as described in McEwan (2001) and Yoshiyama and others (1996). Fish were collected at each sampling location throughout a continuous stream reach (i.e., there are no barriers between actual collection sites within each sampling location) to minimize collection of closely related individuals that would bias the population genetic results.

Figure 1 Sampling locations for Central Valley steelhead rainbow trout.

Table 1 Central Valley steelhead rainbow trout sampling locations.

Sample Location	*Above/Below Barrier*	*Comments*
1. Sacramento River mainstem below Keswick Dam	Below barrier	Collection focused on "river trout" to determine if they differ genetically from steelhead and are reproductively segregated
2. Battle Creek		Weir at hatchery
3. Cottonwood Creek	Below barrier	Self-sustaining stocks in headwaters within steelhead historical range
4. Mill Creek	Below barrier	Mill and Deer creeks represent one of the last remaining intact and accessible small stream systems in the Sacramento River system, and have healthy, self-sustaining populations; hence, they are good candidates to examine population structure of relatively unimpacted populations
5. Deer Creek, downstream of lower falls.		
6. Stony Creek	Above barrier	Self-sustaining stocks in headwaters within steelhead historical range
7. Putah Creek	Above barrier	Self-sustaining stocks above Lake Berryessa
8. Feather River	Below barrier	Low-flow channel
9. Feather River Hatchery		
10. Lower Yuba River	Below barrier	Below Englebright Dam
11. Upper Yuba River	Above barrier	Above New Bullards Bar Dam
12. Lower American River	Below barrier	Below Nimbus Dam
13. Middle Fork American River	Above barrier	Below Rubicon River confluence
14. Nimbus Fish Hatchery		
15. Antelope Creek	Below barrier	Below confluence of north and south forks
16. Calaveras River	Below barrier	Below New Hogan Dam
17 Lower Stanislaus River	Below barrier	Below Goodwin Dam
18. Upper Stanislaus River	Above barrier	Below Beardsley Dam
19. Lower Tuolumne River	Below barrier	Below La Grange Dam
20. Upper Tuolumne River	Above barrier	Between New Don Pedro Reservoir and Yosemite National Park Boundary
21. Kings River	Above barrier	Self-sustaining stocks in headwaters within steelhead historical range

Adult steelhead were collected whenever possible. However, our collections focused mostly on juvenile fish because they are much easier to sample. Fish were captured by electrofishing, hook and line, rotary screw traps, and beach seining. We took caudal fin tissue samples (approximately 2 square millimeters) from 50 to 100 individuals per sampling location. Fish were returned to the stream alive after sampling. Tissue samples were air dried, processed at DFG's Salmonid Genetic Tissue Archive, and shipped to the geneticist. Both DFG and USFWS subcontracted with Dr. Jennifer Nielsen from the US Geological Survey's Alaska Science Center, Conservation Genetics Laboratory, to perform the genetic analyses[1]. A total of 1,570 steelhead rainbow trout tissue samples were analyzed.

DNA was extracted from the tissue samples, amplified, and analyzed using standard methods. Thirteen microsatellite loci from the published literature were used. Tissue samples were analyzed for microsatellite allelic diversity within and among populations. Genetic data were analyzed using a variety of software from different statistical packages. Two loci were found to be out of Hardy-Weinberg equilibrium in over 80% of the sample populations and were dropped from further analysis. Genetic distance values reflecting the proportion of shared alleles between individuals and groups of individuals were determined and used to graphically depict genetic relationships and population structure. An unrooted Neighbor-Joining tree (NJ) was generated. Genetic relationships depicted in the consensus NJ tree were tested using random bootstrap replications (n = 2,000) to assess the reproducibility of branching patterns (Nielsen and others 2003). Bootstrap values are expressed as percentages.

1. The final technical report submitted to DFG and USFWS was written by Nielsen and others (2003); it includes the results from both studies. The original report is available from the author.

Results and Conclusions

This study found that there is significant steelhead genetic population structure throughout the Central Valley (Nielsen and others 2003). Pairwise population comparisons showed significant differentiation in all but 2% of the population-pair comparisons. Analysis of molecular variance showed that microsatellite diversity was highest within populations (88.67%) and lowest among populations (11.33%). After dividing the populations into the two primary drainages, the same analysis showed that microsatellite diversity was highest for individuals within populations (92.39%) and was lowest between the Sacramento and San Joaquin drainages (0.13%). The lack of genetic divergence between the Sacramento and San Joaquin river drainages most likely reflects a common ancestry. However, there is a relatively high level of genetic population structuring within the individual rivers of each drainage area. This genetic diversity and population structuring should be carefully considered before carrying out any future conservation and restoration actions to preserve existing patterns of genetic diversity.

There are significant differences in the allelic frequencies between steelhead rainbow trout samples collected above impassable dams and those collected below dams on several large rivers: American, Stanislaus, Tuolumne, and Yuba rivers. This suggests some degree of genetic separation. A more thorough analysis may allow inference on the direction and duration of such isolation between populations above and below barriers in the Central Valley (Nielsen and others 2003).

Hatchery populations (CNFH, Nimbus Hatchery, and Feather River Hatchery) are genetically similar to steelhead rainbow trout populations in close proximity, suggesting gene flow among these populations or the common ancestry and local origins of the hatchery stock (Nielsen and others 2003). CNFH stock was derived from steelhead collected from the upper Sacramento River from 1947 through 1984. Feather River Hatchery stock is from local origins, but Nimbus Hatchery stock is of mixed origin and includes fish originally collected from the Eel River. The hatchery-wild gene flow is found only at the local scale regardless of hatchery origin. Nielsen and others (2003) note that because hatchery stocks do not have unique diagnostic microsatellite alleles we cannot estimate rates of gene flow or introgression. Other molecular markers and fine scale sampling are needed to obtain this type of information.

Genetic relationships and population structure depicted in the unrooted NJ tree (Figure 2) show some population associations that are intuitive and are supported by relatively high bootstrap values. The clustering of the three hatchery populations with nearby natural populations is well supported by the bootstrap values (the branching pattern shown was observed in ≥ 50% of the 2,000 bootstrap replicates). Samples from CNFH and the upper Sacramento River cluster together, as do samples from Feather River Hatchery and the lower Feather River, and Nimbus Hatchery and the lower American River. Samples from Deer, Mill, and Antelope creeks, which are close to each other geographically, also cluster together.

Other associations were more difficult to interpret, such as the grouping of the upper portions of the Tuolumne, Stanislaus, American, and Yuba rivers. A more thorough investigation is needed to determine if there is shared ancestry of these populations not influenced by hatchery fish or if these associations are due to the influence of introduced rainbow trout stocked above dams (Nielsen and others 2003). Until further studies are conducted we cannot make any conclusions about the presence of presumed native populations above these barriers or their potential use as donor stock. Other associations—such as the Kings River and Stony Creek and the grouping of the Calaveras River, Putah Creek, lower American River, and Nimbus Hatchery—will also need further examination.

Lastly, the genetic analyses showed that most Central Valley steelhead rainbow trout stocks have undergone a recent reduction in population size.

Recommendations for Future Studies

Although this study provided much-needed information on the genetic and population structure of Central Valley steelhead, there are still several questions that can only be answered by conducting additional studies. Recommended research includes:

- A complete genetic analysis of all Central Valley hatchery rainbow trout stocks to get better information on the distribution of hatchery and wild stocks, and impacts of hatchery fish on wild fish genetic diversity.

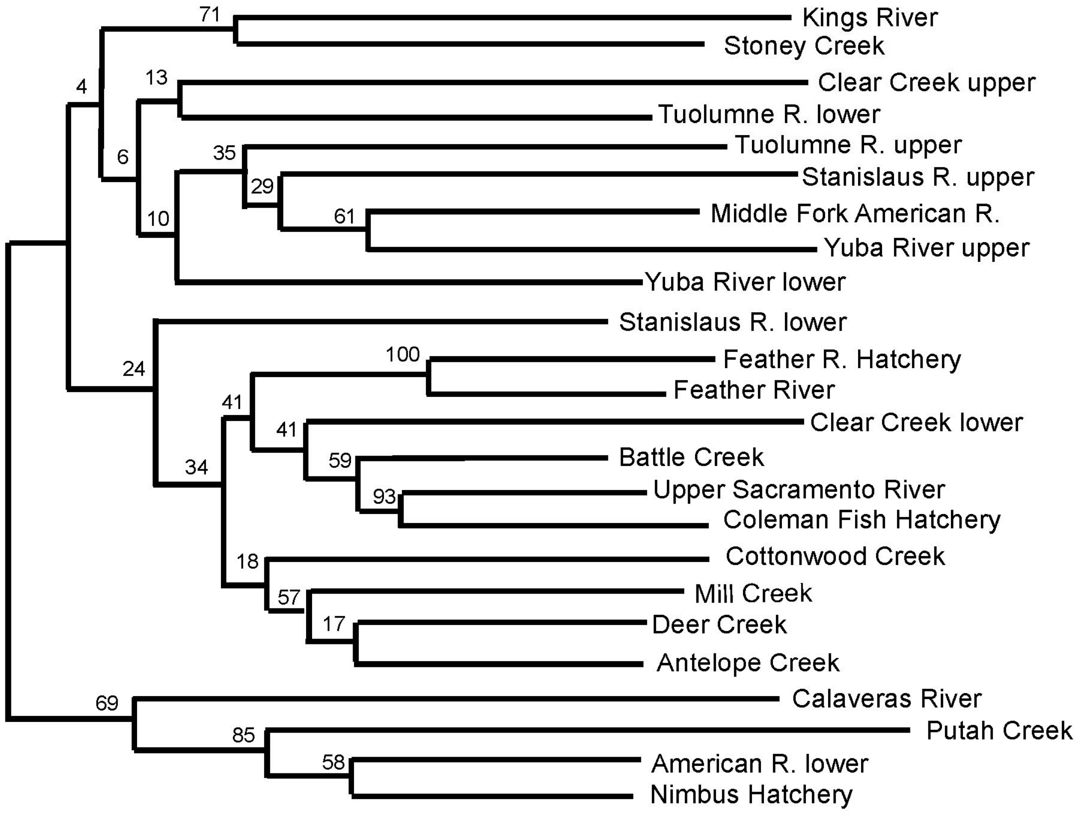

Figure 2 Unrooted Neighbor-Joining tree based on Cavalli-Sforza and Edwards chord distance for the Central Valley system derived from allelic variation at 11 microsatellite loci. Branches with bootstrap values (2,000 replicate trees) are provided.

- Additional genetic analysis of steelhead rainbow trout populations above and below barriers to determine if native stocks of steelhead remain isolated above artificial barriers. These studies should be done on a finer scale for specific watersheds such as the American, Merced, San Joaquin, Stanislaus, Tuolumne, and Yuba rivers.

- Genetic analysis to describe and compare the genetic profiles and relationships of naturally spawning Central Valley steelhead populations with naturally spawning populations along the California coast. This work is currently being conducted by the NOAA Fisheries' Southwest Fisheries Science Center in Santa Cruz.

Detailed examination of hatchery stocking records may provide some insight into several of the unexplained relationships shown in the NJ tree.

Next Phase

DFG has obtained funding from AFRP to evaluate the distribution and relationship of different life-history forms of rainbow trout within the Central Valley. This will build on the genetic population structure study and provide complementary information on population structure using a different technique. The question we are asking is: do the different life-history forms (e.g., steelhead, resident, potamodromous, estuarine) of Central Valley rainbow trout maintain distinct, reproductively isolated populations or do they comprise a single, polymorphic population within stream systems? The life history of individual fish will be determined by comparing strontium to calcium ratios across a transect of the otolith (i.e., ear bones). This will allow us to determine both the life history of the individual fish, as well as the mother. If the life histories of the fish and its mother are different, this indicates that fish are capable of producing offspring that differ in their life-history expression; hence the life-history forms are not reproductively isolated. Recent microchemical analysis of strontium to calcium ratios from three rainbow trout from the Calaveras River provides evidence that some Central Valley rainbow trout populations are polymorphic (McEwan 2001).

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Historic Sedimentation in Sacramento-San Joaquin Delta

Andrey B. Shvidchenko, Robert C. MacArthur, and Brad R. Hall (Northwest Hydraulic Consultants), ashvidchenko@nhc-sac.com

Introduction

Sediment transported to the Sacramento-San Joaquin Delta is an essential resource that forms the estuarine ecosystem and significantly affects navigation, flood control projects, fisheries, water quality, water-use projects, recreation, floodplain restoration, and subsidence reversal projects. Most of sediment supplied to the Delta is carried by the Sacramento and San Joaquin rivers; but some sediment also enters from the Yolo Bypass and the Mokelumne and Cosumnes rivers, as well as from several smaller streams.

The supply of sediment to the Delta has changed drastically over the last 150 years. The discovery of gold in the Sierra Nevada in 1848 triggered a gold rush, which led to huge amounts of debris being dumped into the rivers from uncontrolled hydraulic mining for gold. Although hydraulic mining was terminated in 1885, the transportation of residual mining debris into the Delta and further to the San Francisco Bay system continued until the early 1940s. The reclamation of vast floodplain areas by building levees beginning in the late 1800s and the channelization of streams for flood control restricted floodwaters to the main river channels, increased flow velocities and sediment transport capacities, and thereby also contributed to the changes in the historic sediment transport pattern. The construction and operation of upstream reservoirs for water storage and flood control reduced high flows, increased low flows, and trapped large amounts of sediment, causing a reduction of sediment supply to the Delta. The construction of large water diversion facilities significantly altered flow and sediment transport patterns in the Delta streams. The construction and maintenance of deep water ship channels resulted in extraction of a large amount of alluvium and affected sediment transport in the Delta area. All these anthropogenic alterations had an impact on how much sediment reaches and moves through the Delta.

The purpose of this paper is to briefly review available information on sediment movement in the Sacramento-San Joaquin Delta, present recent findings on the Delta sediment budget, analyze historic sediment budget trends, and provide insight on future trends of the Delta's sediment loads.

Previous Investigations

The sediment transport in the Delta and the San Francisco Bay system has been studied extensively since the beginning of the 20th century. Gilbert (1917) estimated that sediment inflow to the Delta averaged about 2,000,000 cubic yards annually prior to the discovery of gold in 1848. During the subsequent 65-year period of 1849-1914, hydraulic mining resulted in a total of 700,000,000 cubic yards of waste flowing into rivers draining to the Delta. The average annual amount of material of approximately 36,500,000 cubic yards was received by rivers during this period, of which about 12,100,000 cubic yards was deposited within the mountain and piedmont reaches, 1,500,000 cubic yards was deposited in channels of valley rivers, 4,500,000 cubic yards was deposited on inundated lands, and 18,400,000 cubic yards passed into the San Francisco Bay system. The figures obtained for valley rivers and inundated lands amount to 6,000,000 cubic yards per year, which can be used as an approximate estimate of sediment deposits in the Delta area. Gilbert (1917) further predicted that hydraulic mining effects would continue for about 50 years after 1914, with annual sediment transport averaging not less than 8,000,000 cubic yards.

In 1930 the US Army Corps of Engineers (USACE) made a comprehensive investigation of the effect of sedimentation on proposed barriers within the San Francisco Bay area (Grimm 1931). The studies indicated that during 1905-1930 the average annual volume of suspended sediment moved by the Sacramento River to the Delta was 4,250,000 cubic yards. Suspended sediment supply from other streams was estimated at approximately 1,500,000 cubic yards annually. Grimm (1931) also provided results of measurements of bed load in Suisun Bay at Chipps Island during the low water season of 1930. The measurements were made during 40 days and included all tidal phases. The data indicated an average daily movement downstream of about 80 cubic yards with an upstream movement of about 40 cubic yards or a net movement of 40 cubic yards per day downstream.

In 1954, the USACE prepared a review of sedimentation in the San Francisco Bay system and the Delta area (USACE 1954). The average annual sediment inflow from the Central Valley was estimated at 3,360,000 cubic yards using watershed sediment yield rates developed by a Soil Conservation Service study.

A study by the California Department of Water Resources (DWR) estimated the sediment entering the Delta from the Central Valley at 4,000,000 cubic yards annually (DWR 1955). The analysis was based on relation of streamflow to suspended load and bed load.

The studies of Gianelli and Murray Consulting Civil Engineers (1964) indicated that during 1940-1951 an average of about 1,130,000 cubic yards of sediment were deposited annually in the Sacramento River between Junction Point and Collinsville, while during 1951-1961 an average of about 757,000 cubic yards annually were deposited in the reach.

Porterfield and others (1961) used the suspended load data collected by the US Geological Survey (USGS) during 1957-1959 to compute total sediment loads at key sediment measurement sites and to estimate sediment loads for unmeasured streams. The average annual sediment inflow to the Delta during the 1957-1959 period was estimated at 5,200,000 tons (7,200,000 cubic yards), of which 4,400,000 tons (85%) was supplied from the Sacramento River basin and 800,000 tons (15%) from the San Joaquin River basin. The long-term sediment load based on 1959 conditions was estimated at 5,000,000 tons (6,900,000 cubic yards) per year.

Smith (1963, 1966) analyzed channel maintenance dredging data for 1930-1959 and obtained an average annual deposition in the Delta of 1,600,000 cubic yards. The sediment diverted into the Delta-Mendota Canal through the pumping plant at Tracy in 1960 was estimated at 307,000 cubic yards (200,000 tons). Adopting sediment inflow to the Delta at 6,900,000 cubic yards (5,000,000 tons), Smith (1963) obtained the average annual outflow from the Delta to Suisun Bay under 1960 conditions of 5,130,000 cubic yards.

According to Homan and Schultz (1963), annual deposition in the Delta amounted to 1,600,000 cubic yards. Schultz (1965) estimated annual sediment inflow into the Bay system from all sources at 10,000,000 cubic yards, with an estimated 1,500,000 cubic yards deposited in the Delta.

Krone (1966, 1979) estimated suspended sediment inflow to the San Francisco Bay system by establishing a relation between annual water discharge and measured suspended sediment production for both the Sacramento and San Joaquin rivers. This relation was applied to historic water flows to estimate long-term sediment loads under 1960 conditions. The average annual suspended sediment supply to the Delta was estimated at 3,750,000 tons and suspended sediment outflow from the Delta at 3,350,000 tons. If the bed load is taken to be 6.5% of the total sediment load (Krone 1979), the total sediment inflow to and outflow from the Delta under 1960 conditions would be 4,000,000 and 3,600,000 tons, respectively.

Porterfield (1980) used suspended sediment data collected by the USGS during 1957-1966 to estimate sediment discharge to the Delta and the bays downstream. The results indicated average annual total sediment inflow to the Delta during this period of 4,570,000 tons, of which 3,980,000 tons (87%) was supplied from the Sacramento River basin and 590,000 tons (13%) from the San Joaquin River basin. The long-term sediment inflow to the Delta was estimated at 5,310,000 tons annually. Porterfield (1980) also provided estimates of bed load in the Sacramento River at Sacramento by tractive force equations. The estimated average bed load transport rate was about 44,000 tons per year and contributed only 1.4% of the total sediment load.

A sediment monitoring program conducted by the USGS during the period of 1961-1979 indicated the average annual total sediment load of 3,250,000 tons for the Sacramento River at Sacramento and 580,000 tons for the Yolo Bypass near Woodland (USACE 1983).

Beeman (1992) estimated that 6,100,000 cubic yards (4,400,000 tons) of sediment entered the Delta in 1990. Water exports from the Delta removed 1,600,000 cubic yards (1,100,000 tons) in the form of suspended sediments, dredging removed another 500,000 cubic yards (600,000 tons), and the remaining 4,000,000 cubic yards (2,700,000 tons) of sediment passed through the Delta to the Bay.

Anderson (1994) compiled available information on flow conditions and sediment movement in and around the Delta and provided a historical perspective on the changes in sediment loads in the area based on earlier publications.

Krone (1996) used recent suspended sediment data in conjunction with existing water operating conditions to obtain an average annual sediment outflow from the Delta to the San Francisco Bay system of 5,900,000 cubic yards (2,600,000 tons) under 1990 conditions.

Williams (2001) states that, due to effect of dams and water diversions, there has been a continuing decline in sediment delivery to the Delta in the 20th century. He speculates that average annual sediment inflow to the Delta is now probably only about 4,500,000 cubic yards, which is about half of what it was in the 1960s and barely double that of the undisturbed landscape of 200 years ago.

McKee and others (2002) used suspended sediment data collected by the USGS at Mallard Island to estimate suspended sediment flux entering San Francisco Bay from the Sacramento-San Joaquin Delta. The data were collected every 15 minutes during 1994-1998 using optical backscatter sensors. Daily suspended load was estimated by combining estimated daily average water outflow from the Delta with daily average suspended sediment data. On days when no data were available, suspended load was estimated using linear interpolation across the data gaps. Average annual suspended sediment outflow at Mallard Island during 1994-1998 was 2,300,000 tons (5,200,000 cubic yards), with the long-term average estimated at 1,100,000 tons (2,500,000 cubic yards).

From 1998 to 2000 the USGS measured movement of dunes in the Sacramento River at Garcia Bend (just upstream of Freeport) and tidally affected Threemile Slough using repeated bed form mapping with an array of echo-sounders (Dinehart 2002). Mean bed form transport rate was calculated from riverbed profiles and ranged from about 34 to 160 tons per day in the Sacramento River and was 110 tons per day in Threemile Slough. The bed load data collected in the Sacramento River were limited to rather low flow conditions. During floods, bed forms were washed away, which did not allow estimation of bed load transport rate from channel surveys.

Table 1 summarizes the components of the annual sediment budget related to the Sacramento-San Joaquin Delta from the previous studies. Sediment transport in the table is expressed in weight units. The data was originally presented in volumetric units and has been converted to approximate weight quantities using the USGS densities of 50 lb/ft^3 for suspended sediment deposits and 90 lb/ft^3 for channel deposits (Porterfield and others 1961). The previous investigations of sediment transport in the Delta were limited in accuracy due to lack or relatively short time series of sediment data. Most of the estimates of sediment loads were based solely on suspended sediment measurements conducted in the Delta area since the late 1950s. Little was known about the character and amount of bed load transport until recent measurements by the USGS from 1998 through 2000 (Dinehart 2002).

Recent Findings

Recently, Northwest Hydraulic Consultants (NHC) assessed existing conditions for the sediment budget of the Delta using the most up-to-date information on hydrodynamics, suspended load, bed load, water use, and dredging (NHC 2003). Suspended sediment inflows to and outflows from the Delta were estimated using updated suspended sediment data collected by the USGS on key streams comprising the Delta. Suspended loads in the Sacramento and San Joaquin rivers were determined using long time-series of daily suspended sediment data available for these streams. Suspended loads in the streams with episodic suspended sediment measurements were estimated using daily flow records in conjunction with averaged suspended sediment rating curves fitted to the measured data. Suspended loads in the tidally affected areas were estimated using continuous suspended sediment concentration and flow data collected by the USGS at selected locations in the Delta. Bed load transport in the Delta streams was estimated by selecting a sediment transport equation which best fit the limited measured bed load data and using this equation in conjunction with the measured hydrodynamic and channel geometry data.

Long-term average annual sediment loads in the Delta streams as estimated by NHC are summarized in Figure 1 and Table 2. According to the NHC (2003) findings, the average annual suspended sediment inflow to the Delta from the Sacramento River and Yolo Bypass totals 3,120,000 tons and average annual bed load inflow is 150,000 tons. The San Joaquin River supplies annually an average of 340,000 tons of suspended sediment and 80,000 tons of bed load. Together, the Mokelumne and Cosumnes rivers supply an average 134,000 tons of suspended sediment and approximately 6,000 tons of bed load each year. Suspended load constitutes from 81% to 96% and bed load from 4% to 19% of the total sediment loads in these rivers.

Average annual suspended sediment outflow from the Delta to Suisun Bay is estimated at 1,200,000 tons and bed load outflow at 70,000 tons. Suspended load constitutes 95% and bed load constitutes 5% of the total sediment outflow to Suisun Bay. In addition, an estimated 370,000 tons of suspended sediment is exported to the Delta-Mendota Canal and 460,000 tons to the California Aqueduct.

The above values represent long-term, statistically averaged characteristics. There could be a few-fold variation in individual annual sediment loads around the long-term average amounts depending on specific hydrologic and sediment supply conditions.

Table 1 Summary of sediment transport studies for the Delta from various sources.

Conditions as of	Source	*Components of annual sediment budget (tons)*			
		Inflow	*Deposits*[a]	*Outflow*	*Export*[b]
1848	Gilbert (1917)	1,400,000			
1849-1914	Gilbert (1917)	17,000,000	4,000,000	13,000,000	
1930	Grimm (1931)	3,900,000[c]			
1954	USACE (1954)			2,400,000	
1955	DWR (1955)			2,700,000	
1959	Porterfield and others (1961)	5,000,000			
1960	Smith (1963, 1966)	5,000,000	1,200,000	3,600,000	200,000
1960	Krone (1966, 1979)	4,000,000		3,600,000	
1963	Homan and Schultz (1963)		1,900,000		
1965	Schultz (1965)		1,800,000		
1966	Porterfield (1980)	5,310,000			
1990	Beeman (1992)	4,400,000	600,000	2,700,000	1,100,000
1990	Krone (1996)			2,600,000	
1998	McKee and others (2002)			1,100,000[c]	
2000	Williams (2001)	3,200,000			
2000	NHC (2003)	3,920,000	1,820,000	1,270,000	830,000

Note: [a] Include dredged material, [b] Water diversion, [c] Suspended load only.

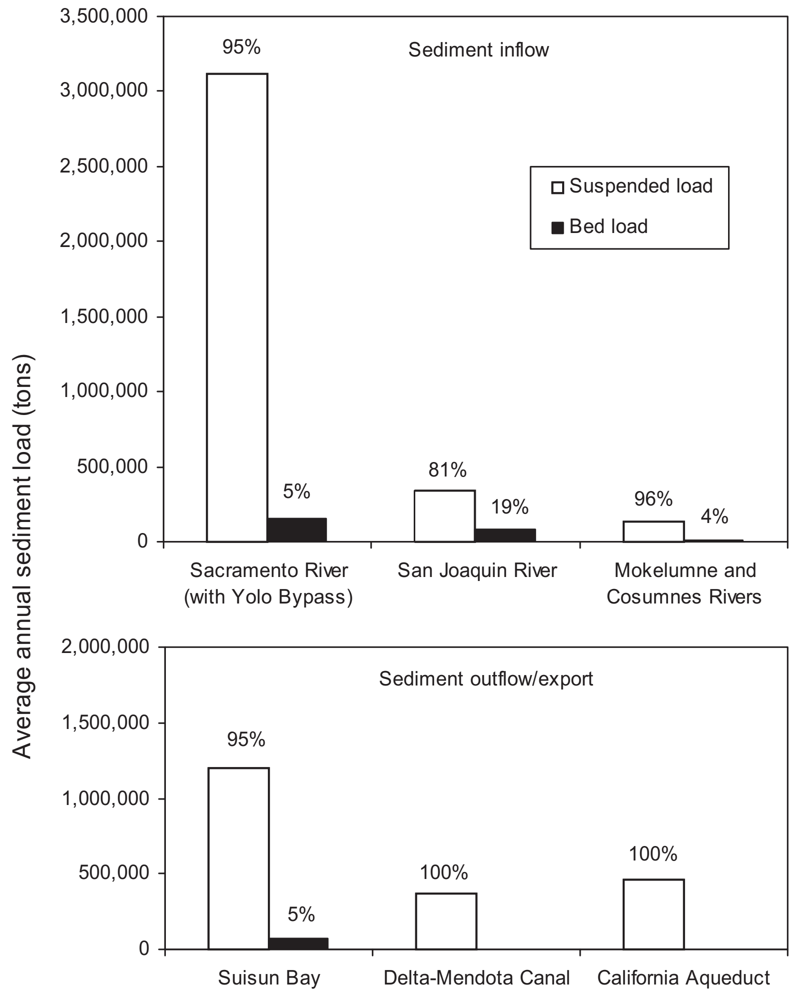

Figure 1 Average annual suspended and bed loads and their proportions in total sediment loads.

Table 2 Estimated average annual sediment loads in Delta streams.

	Long-term average annual sediment load (tons)		
Streams	*Suspended load*	*Bed load*	*Total load*
Sediment inflow to Delta			
Sacramento River (with Yolo Bypass)	3,120,000	150,000	3,270,000
San Joaquin River	340,000	80,000	420,000
Mokelumne and Cosumnes Rivers	134,000	6,000	140,000
Sediment outflow/export from Delta			
Suisun Bay	1,200,000	70,000	1,270,000
Delta-Mendota Canal	370,000	0	370,000
California Aqueduct	460,000	0	460,000

Existing Conditions Sediment Budget

According to the NHC (2003) data presented in Figure 1 and Table 2, the Sacramento River is the primary supplier of sediment to the Delta. The long-term, average annual, total sediment inflow from the Sacramento River (including the Yolo Bypass) is estimated at 3,270,000 tons. The San Joaquin River supplies an estimated 420,000 tons of sediment, and the Mokelumne and Cosumnes rivers supply approximately 140,000 tons of sediment each year. An allowance of 90,000 tons per year was added for other minor streams and creeks not covered by the measurements, in accordance with Porterfield (1980). Thus, total average annual sediment inflow to the Delta is estimated at approximately 3,920,000 tons, of which 83% is derived from the Sacramento River and the Yolo Bypass, 11% from the San Joaquin River, 4% from the Mokelumne and Cosumnes rivers, and 2% from other minor streams tributary to the Delta.

Of the sediment supplied annually to the Delta, on average an estimated 1,270,000 tons (33%) is transported to Suisun Bay and a total of 830,000 tons (21%) is exported through the water pumping facilities to the Delta-Mendota Canal and California Aqueduct. Possible sediment outflow through other minor export facilities was assumed negligible. The remainder of 1,820,000 tons (46% of the sediment supplied) is deposited in the Delta each year, of which about 900,000 tons is dredged for navigation and levee maintenance purposes and approximately 920,000 tons is deposited in unnavigable, shallow sloughs of the Delta.

The estimated components of the long-term average annual sediment budget of the Delta are summarized in Table 3 and illustrated in Figure 2. Given the significant natural variability of sediment transport phenomena and measurement errors inherent in the field measurement data used in the analysis, it is believed that likely accuracy errors in the above estimates are at least a dozen percent for the sediment inflow and a few dozens percent for the sediment outflow and deposition components of the sediment budget.

Table 3 Sediment budget for existing Delta conditions.

Sediment budget components	*Long-term average annual amount (tons)*
Sediment inflow	3,920,000
Sediment outflow	1,270,000
Sediment export	830,000
Sediment deposition	1,820,000
Dredged material	900,000
Balance (net deposition)	920,000

Historic Changes in Sediment Loads

The results from the NHC (2003) analysis are compared with those from previous studies in Table 1. It is seen that sediment loading to the Delta has changed dramatically in the last one and a half centuries since large-scale settlement followed the California Gold Rush. Hydraulic gold mining operations during 1849-1885 caused a ten-fold increase of sediment delivery to the Delta from 1,400,000 to 17,000,000 tons per year. After hydraulic mining was shut down, sediment inflow to the Delta decreased to about 4,000,000-5,000,000 tons in the mid-1900s and further down to around 3,000,000-4,000,000 tons by the end of the 20th century. However, the present sediment inflow is still 2-3 times higher than Gilbert's (1917) estimate of pre-disturbance sediment inflow.

Estimates of sediment outflow from the Delta to the San Francisco Bay system demonstrate a similar historic pattern. Average annual sediment outflow declined from 13,000,000 tons at the beginning of the 20th century down to about 2,000,000-4,000,000 tons mid-century, and then to 1,000,000-2,000,000 tons by the end of the century. Estimated deposition of sediment in the Delta decreased accordingly from 4,000,000 tons at the beginning of the 20th century to about 1,000,000-2,000,000 tons for the second half of the century. At the same time, sediment export from the Delta through the water export facilities increased from an estimated 200,000 tons per year in 1960 to 830,000-1,100,000 tons per year in the late 1900s.

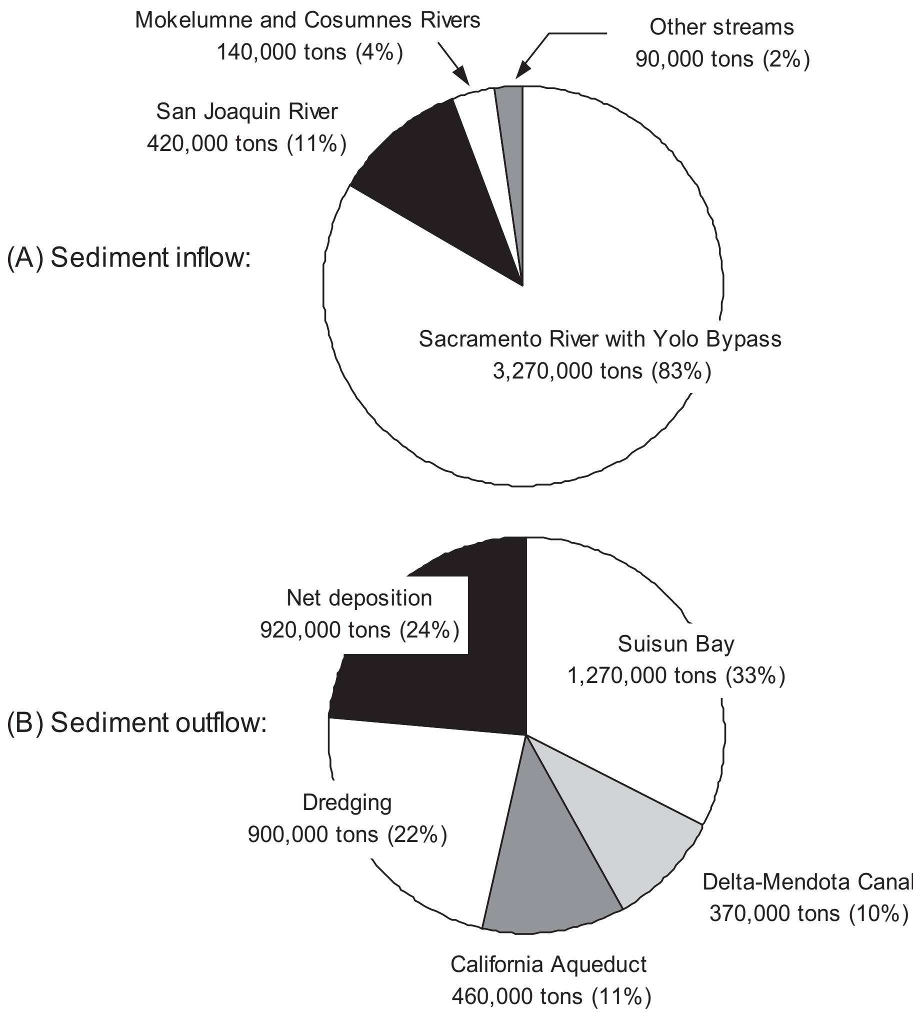

Figure 2 Average annual sediment budget for the Delta.

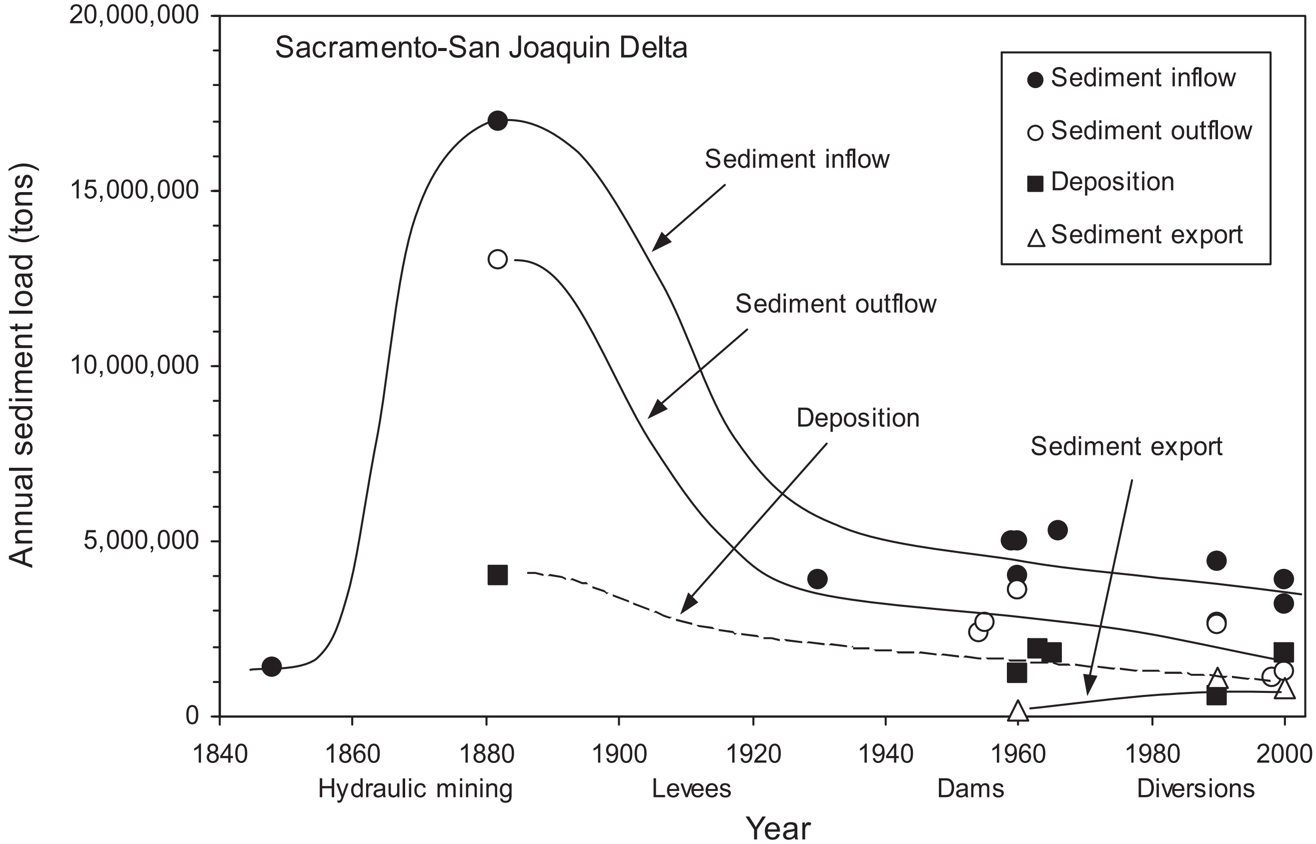

Figure 3 Historic changes in Delta sediment loads.

The historic changes in the Delta sediment loads are graphically illustrated in Figure 3. The drastic change of sediment transport conditions in the Delta streams over the last century and a half was caused by a combination of various human activities. The combination of overgrazing, deforestation, floodplain reclamation, river channelization, and, most importantly, hydraulic mining for gold caused huge increases in sediment loads in the Delta system. In the 20th century, sediment loads started to decline as hydraulic mining was stopped, dams were built that captured sediment and reduced flood flows, and water diversion facilities were constructed that reduced river flows and diverted sediment from the Delta streams. The available estimates demonstrate a rapid decline of sediment loads in the first half of the 20th century, with the following gradual steady reduction of the loads over the last half of the century. If the trend continues into the future and water export operations remain on the same level, average annual sediment inflow to the Delta will likely decline to about 3,000,000 tons in the next few decades, sediment outflow from the Delta to the San Francisco Bay system will be about 1,000,000 tons per year, and sediment deposition within the Delta will amount to around 1,000,000 tons per year.

Summary

The sediment budget for the existing conditions in the Sacramento-San Joaquin Delta is based on the most recent information on hydrodynamics, sediment transport, water use, and dredging and can be summarized as follows:

- Long-term average annual total sediment inflow to the Delta is 3,920,000 tons, of which 3,270,000 tons (83%) is derived from the Sacramento River and the Yolo Bypass, 420,000 tons (11%) from the San Joaquin River, 140,000 tons (4%) from the Mokelumne and Cosumnes rivers, and 90,000 tons (2%) from other minor streams and creeks.

- Of the total amount of sediment delivered to the Delta, on average 1,270,000 tons (33%) is transported to Suisun Bay, 830,000 tons (21%) is withdrawn through the water export facilities, and 1,820,000 tons (46%) is deposited in the Delta channels and sloughs each year.

- Of the sediment deposited, about 900,000 tons is annually dredged for to improve navigation and help maintain levees, leaving a net sediment deposition in the Delta of 920,000 tons.

The figures presented here are long-term, statistically average values. There could be significant (a few-fold) variations in individual annual sediment loads depending on specific hydrologic and sediment supply conditions.

The historic trend demonstrates a rapid decline of sediment loads in the Delta streams at the beginning of the 20th century, followed by a gradual steady reduction of sediment loads over the last half a century. If the trend continues in the future, it is expected that in the next few decades, average annual sediment inflow to the Delta will likely decline to about 3,000,000 tons, sediment outflow will be of the order of 1,000,000 tons, and sediment deposition will be somewhat around 1,000,000 tons. This has implications for sustainable management of the Delta's resources, protection and restoration of the estuarine ecosystem, navigation channel maintenance, flood hazard and control, aquatic habitat characteristics, and halting and reversal of continuing subsidence of the reclaimed Delta islands.

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Recent Research Published in the Open Literature

Compiled by Ted Sommer (DWR), tsommer@water.ca.gov

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DELTA WATER PROJECT OPERATIONS

Kate Le (DWR), kle@water.ca.gov

From April through June 2004, river flow for the San Joaquin River was stable and ranged between 34 and 96 cubic meters per second (m^3/s) (1,204 and 3,382 cfs); whereas Sacramento River and Net Delta Outflow Index (NDOI) flows fluctuated. Sacramento River flow ranged between 323 and 1,021 m^3/s (11,408 cfs to 36,057 cfs), and the NDOI ranged between 193 and 888 m^3/s (6,806 cfs and 31,346 cfs) as shown in Figure 1. Sacramento River and NDOI flows increased in early April to meet the X2 standard, but then started to decline for the Vernalis Adaptive Management Program (VAMP) in mid-April to about 300 m^3/s (12,000 cfs) and held steady at this rate to the end of April. In May, Sacramento and NDOI flows continued to be steady for VAMP, ranging between 283 and 425 m^3/s (10,000 cfs and 15,000 cfs), and began to diverge in June. NDOI continued to decline in June, whereas Sacramento River flow increased by 57 m^3/s (2,000 cfs) and held steady between 425 and 453 m^3/s (15,000 cfs to 16,000 cfs) for the remainder of June to offset the slight increase in pumping at the State Water Project. There was little precipitation activity during this period. Only five precipitation events occurred, and four of the events were less than 0.20 inches. Precipitation during this period ranged from 0.04 inches (May 27, 2004) to 0.35 inches (April 18, 2004).

During the April through June 2004 period, export actions at SWP and CVP (Figure 2) generally operated to either X2, export-to-inflow (E/I), outflow, VAMP, or Environmental Water Account (EWA). However, on June 2, 2004, an unexpected levee break at Upper Jones Tract added operational challenges to both water projects for June. SWP pumping ranged between 1 and 166 m^3/s (35 cfs and 5,876 cfs), and CVP pumping ranged between 15 and 126 m^3/s (518 cfs and 4,433 cfs). The following is a summary of the reasons for the operational actions at both water projects during this period:

- Early April 2004: Reduced exports to meet X2 standard.
- Mid-April to mid-May 2004: Exports reduced for VAMP.
- Late May 2004: Exports remain low due to EWA action.
- June 1, 2004: Exports ramping up after VAMP.
- June 2, 2004: The SWP shut down pumping for maintenance work and the CVP shut down pumping due to a levee break at the Upper Jones Tract (in the Delta).
- June 6, 2004: Both water projects resumed pumping at a steady rate to minimize high saline water intake resulting from the levee break a few days earlier.
- June 17, 2004: The CVP gradually increased pumping to about 122 m^3/s (4,300 cfs) and remained steady at this rate for the remainder of June, whereas the SWP reduced pumping to meet the E/I standard.
- June 20, 2004: The SWP increased pumping slightly, and then began to reduce the flows thereafter to meet outflow standards for the remainder of June.

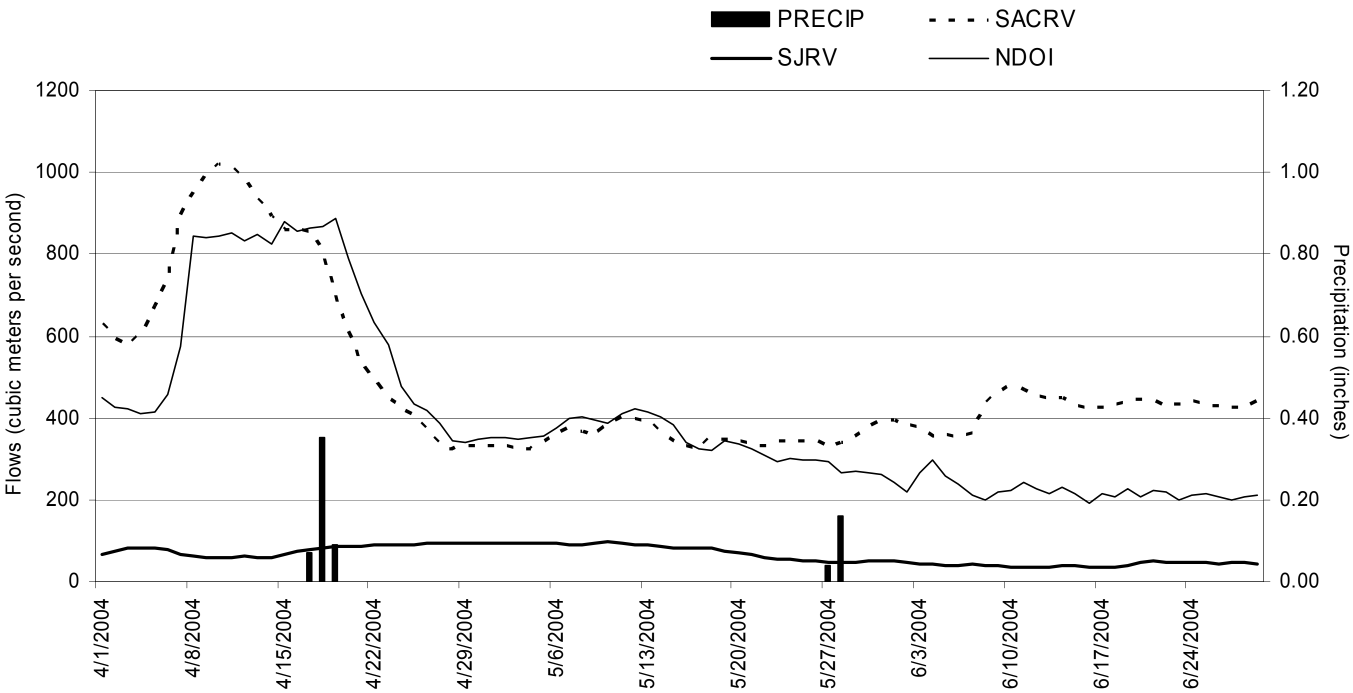

Figure 1 Sacramento River, San Joaquin River, Net Delta Outflow Index, and precipitation, April through June 2004

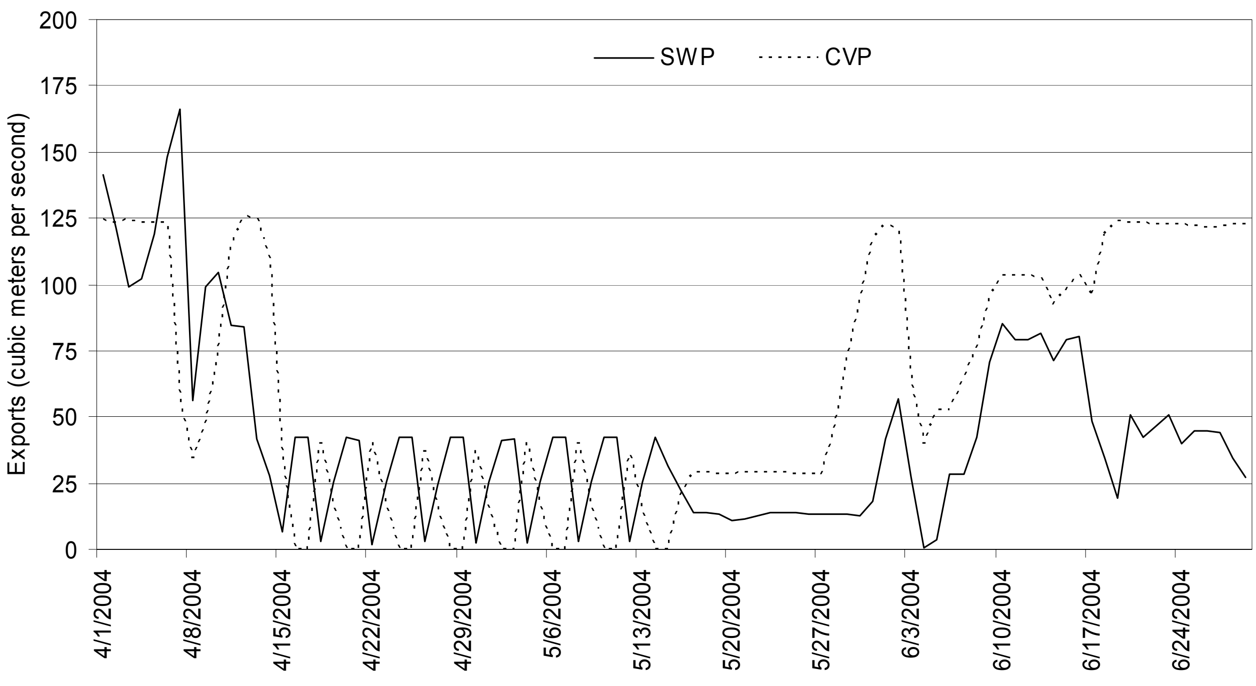

Figure 2 State Water Project and Central Valley Project pumping, April through June 2004

■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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For information about the Interagency Ecological Program, log on to our website at http://www.iep.water.ca.gov. Readers are encouraged to submit brief articles or ideas for articles. Correspondence—including submissions for publication, requests for copies, and mailing list changes—should be addressed to Nikki Blomquist, California Department of Water Resources, P.O. Box 942836, Sacramento, CA, 94236-0001. Questions and submissions can also be sent by e-mail to: nikkib@water.ca.gov.

■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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U.S. Army Corps of Engineers
California Department of Fish and Game
U.S. Fish and Wildlife Service
U.S. Geological Survey
U.S. Environmental Protection Agency

National Marine Fisheries Service

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